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SUSTAINABILITY OF SUGARCANE BAGASSE BRIQUETTES AND CHARCOAL VALUE CHAINS IN KENYA

Results and recommendations from implementation of the Global Bioenergy Partnership Indicators

TECHNICAL REPORT

SEI

World Agroforestry

Kenya Forestry Research Institute KEFRI

Strathmore University
Energy Research Centre

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

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FOREWORD

Dear Readers,

The following report, *Sustainability of Sugarcane Bagasse Briquettes and Charcoal Value Chains in Kenya: Results and Recommendations from Implementation of the Global Bioenergy Partnership (GBEP) Indicators*, assesses the current and future potential of Kenya's bioenergy sector. It outlines the consequences of the widening gap between supply and demand for wood fuel, with the current supply not matching demand in various parts of the country. The report also illustrates key factors that can shape the long-term and periodic monitoring of the sector.

Kenya Vision 2030 has identified energy as one of the enablers of the three pillars of its vision. The level and intensity of commercial energy use will be the key indicator of economic growth and development. Bioenergy, like other energy sources, will continue to play a role in both the traditional and commercial energy mix.

Kenya's Nationally Determined Contribution (NDC) includes four key climate change mitigation targets related to forestry and bioenergy: working towards 10 per cent tree cover of the land area of Kenya; promoting clean energy technologies to reduce overreliance on wood fuel; employing low-carbon and efficient transport systems; and using climate-smart agriculture (CSA) in line with the National CSA Framework.

The 24 GBEP indicators assess the environmental, social and economic aspects of bioenergy use. In this study two critical pathways were chosen: 1) use of sugarcane bagasse briquettes in the tea industry; and 2) household use of charcoal produced on woodlands and farmlands.

I hope that you will find the conclusions and the recommendations presented in this report informative, and that by better understanding the environmental, social and economic impacts of bioenergy use we will be able to sustainably manage this important national resource.

This work was undertaken by four research centres – Stockholm Environment Institute for Africa, Kenya Forestry Research Institute, Strathmore University and the World Agroforestry Centre – with the support of a multi-stakeholder working group. We are grateful for the technical support from the United Nations Environment Programme and for the financial support from the German Climate Initiative (IKI).

Dr Charles Mutai
Director, Climate Change Directorate
Ministry of Environment and Forestry Kenya

ABBREVIATIONS AND ACRONYMS

CO_{2eq}	Carbon dioxide equivalent
CPA	Charcoal producer association
CPG	Charcoal producer group
DALY	Disability-adjusted life-year
FAO	Food and Agriculture Organization
FUCA	Forest users and conservation association
GBEP	Global Bioenergy Partnership
GIS	Geographic information system
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule
GoK	Government of Kenya
HI	Herfindahl Index
IEA	International Energy Agency
ILO	International Labour Organization
KCJ	Kenya Ceramic Jiko
kg	Kilogram
KIPPRA	Kenya Institute for Public Policy Research and Analysis
km	Kilometre
km^2	Square kilometre
KSh	Kenyan shilling
KTDA	Kenya Tea Development Agency
m^3	Cubic metre
MJ	Megajoule
MoE	Ministry of Energy
MEWNR	Ministry of Environment, Water and Natural Resources
MEF	Ministry of Environment and Forestry
MENR	Ministry of Environment and Natural Resources
NO_x	Nitrogen oxides
PM_{10}	Particulate matter 10
SDG	Sustainable Development Goal
SERC	Strathmore Energy Research Centre
SN1	Scenario one
SN2	Scenario two
SO_2	Sulphur dioxide
TPES	Total primary energy supply
UNEP	United Nations Environment Programme
YLL	Number of years of life a person loses
YLD	Number of years that a person lives with disability caused by the disease

1 IMPLEMENTATION OF THE GBEP SUSTAINABILITY INDICATORS FOR BIOENERGY IN KENYA

1.1 Background

The Global Bioenergy Partnership (GBEP) is an international initiative of more than 70 Partners and Observers (referred to as "members"), including governments, intergovernmental organizations and civil society, that work on the sustainability of bioenergy and its contribution to climate change mitigation. The GBEP provides a platform for sharing information and examples of good practice in sustainable bioenergy, and the initiative builds its activities on three strategic areas: sustainable development, climate change, and energy and food security. It also seeks to enhance collaborative project development and implementation, with a view to optimizing the contribution of bioenergy to sustainable development, taking into account environmental, social and economic factors. In December 2011, the GBEP published a report with a set of 24 sustainability indicators for bioenergy (Table 1.1), with contributions from all members and agreed on a consensus basis (Food and Agriculture Organization [FAO] 2011).

Even though several national and regional initiatives have defined their own sustainability criteria for bioenergy (mainly focused on liquid biofuels), the work of the GBEP is unique because it is currently the only initiative that has built consensus among a broad range of national governments and international organizations on the sustainability of bioenergy, with an emphasis on providing measurements useful for informing national-level policy analysis and development. Moreover, the GBEP work addresses all forms of bioenergy. The GBEP sustainability indicators do not feature directions, thresholds or limits and do not constitute a standard, nor are they legally binding on GBEP members.

The GBEP has sought to develop a holistic set of science-based and technically sound indicators for national evaluation of the domestic production and use of modern bioenergy. All members were invited to contribute their respective experience and technical expertise to the development and refinement of the indicators.

The GBEP first developed and provisionally agreed on a list of themes, then established three sub-groups: 1) Environmental – co-led by Germany and the United Nations Environment Programme (UNEP); 2) Social – led by the Food and Agriculture Organization of the United Nations (FAO); and 3) Economic and Energy Security – co-led by the International Energy Agency (IEA) and the United Nations Foundation. These sub-groups undertook the detailed work on the indicators for these themes, which were equally divided among the three sub-group headings. The GBEP report on the sustainability indicators of bioenergy also contains a section listing examples of contextual information about cross-cutting issues relating to the legal, policy and institutional framework of relevance to bioenergy and its ability to contribute to sustainable development.

During the process of developing the indicators, GBEP members used the work of relevant organizations and international processes related to environmental quality, social welfare and sustainable economic development. Some of the relevant international organizations whose work has informed the development of indicators include the IEA, the International Labour Organization (ILO), the United Nations Development Programme (UNDP), UNEP, the FAO, the United Nations Industrial Development Organization (UNIDO) and the World Health Organization (WHO).

The development of the indicators made use of existing guidance documents on sustainable development as discussed in the global community, especially taking into account the Millennium Development Goals, the Commission on Sustainable Development (CSD) and Agenda 21. The GBEP

developed themes that are connected to the social impact of access to modern energy services, notably human health and safety, and rural and social development.

Since the publication of the GBEP Sustainability Indicators (FAO 2011), the Sustainable Development Goals (SDGs) have been internationally accepted. Nearly all of the 17 SDGs are linked to biomass in some way, as either a driver for increased use or as sustainability safeguards (IINAS and IFEU 2018). Furthermore, access to modern energy services from bioenergy for households and businesses can promote social development and poverty reduction, and as such can contribute to achieving various SDGs, including those related to health, education and gender equality (in addition to energy access).

The GBEP developed indicators relevant to the economic themes of sustainability, including those that cover the concepts of economic development, energy security, resource availability and efficiency of use, infrastructure development, and access to technology. Indicators related to these themes were informed by the work of the CSD, international organizations, and agencies and ministries within the governments of GBEP members.

Within the environmental pillar, a number of central themes were considered as part of the discussion of the GBEP Sustainability Indicators, including those related to greenhouse gas emissions, productive capacity of the land and ecosystems, water and air quality, biological diversity and land-use change. These important aspects were discussed and incorporated within relevant indicators and their underlying methodologies.

The development of the indicators was informed by relevant international processes also focusing on these themes, including the Convention on Biological Diversity, the Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change.

The selection criteria for the indicators were relevance, practicality and scientific basis. Additionally, the geographic scale was considered, as well as whether the full set of indicators was balanced and sufficiently comprehensive while still practical.

In Table 1.1, the 24 GBEP Sustainability Indicators are set out under the three pillars, with the relevant themes listed at the top of each pillar. The order in which the indicators are presented has no significance. Full supporting information relating to the relevance, practicality and scientific basis of each indicator, including suggested approaches for their measurement, can be found in FAO (2011).

Table 1.1. The GBEP Sustainability Indicators

ENVIRONMENTAL PILLAR	
THEMES The GBEP considers the following themes relevant, and these guided the development of indicators under this pillar: greenhouse gas emissions; productive capacity of the land and ecosystems; air quality; water availability, use efficiency and quality; biological diversity; and land-use change, including indirect effects.	
INDICATOR NAME	INDICATOR DESCRIPTION
1. Lifecycle greenhouse gas emissions	Lifecycle greenhouse gas emissions from bioenergy production and use, as per the methodology chosen nationally or at the community level, and reported using the GBEP Common Methodological Framework for GHG Lifecycle Analysis of Bioenergy Version One
2. Soil quality	Percentage of land for which soil quality, in particular in terms of soil organic carbon, is maintained or improved out of total land on which bioenergy feedstock is cultivated or harvested
3. Harvest levels of wood resources	Annual harvest of wood resources by volume and as a percentage of net growth or sustained yield, and the percentage of the annual harvest used for bioenergy
4. Emissions of non-greenhouse gas air pollutants, including air toxics	Emissions of non-greenhouse gas air pollutants, including air toxics, from bioenergy feedstock production, processing, transport of feedstocks, intermediate products and end products, and use; and in comparison with other energy sources
5. Water use and efficiency	▪ Water withdrawn from nationally determined watershed(s) for the production and processing of bioenergy feedstocks, expressed as the percentage of total actual renewable water resources and as the percentage of total annual water withdrawals, disaggregated into renewable and non-renewable water sources ▪ Volume of water withdrawn from nationally determined watershed(s) used for the production and processing of bioenergy feedstocks per unit of bioenergy output, disaggregated into renewable and non-renewable water sources
6. Water quality	▪ Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for bioenergy feedstock cultivation, and expressed as a percentage of pollutant loadings from total agricultural production in the watershed ▪ Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents, and expressed as a percentage of pollutant loadings from total agricultural processing effluents in the watershed
7. Biological diversity in the landscape	▪ Area and percentage of nationally recognized areas of high biodiversity value or critical ecosystems converted to bioenergy production ▪ Area and percentage of the land used for bioenergy production where nationally recognized invasive species, by risk category, are cultivated ▪ Area and percentage of the land used for bioenergy production where nationally recognized conservation methods are used

8. Land use and land-use change related to bioenergy feedstock production	▪ Total area of land for bioenergy feedstock production, and as compared to total national surface and agricultural and managed forest land area
	▪ Percentages of bioenergy from yield increases, residues, wastes and degraded or contaminated land
	▪ Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production, including the following (amongst others):
	  o arable land and permanent crops, permanent meadows and pastures, and managed forests;
	  o natural forests and grasslands (including savannah, excluding natural permanent meadows and pastures), peatlands and wetlands

SOCIAL PILLAR	
THEMES The GBEP considers the following themes relevant, and these guided the development of indicators under this pillar: price and supply of a national food basket; access to land, water and other natural resources; labour conditions; rural and social development; access to energy; human health and safety.	
INDICATOR NAME	INDICATOR DESCRIPTION
9. Allocation and tenure of land for new bioenergy production	Percentage of land – total and by land-use type – used for new bioenergy production where: ▪ a legal instrument or domestic authority establishes title and procedures for change of title; and ▪ the current domestic legal system and/or socially accepted practices provide due process and the established procedures are followed for determining legal title
10. Price and supply of a national food basket	Effects of bioenergy use and domestic production on the price and supply of a food basket, which is a nationally defined collection of representative foodstuffs, including main staple crops, measured at the national, regional, and/or household level, taking into consideration: ▪ changes in demand for foodstuffs for food, feed and fibre; ▪ changes in the import and export of foodstuffs; ▪ changes in agricultural production due to weather conditions; ▪ changes in agricultural costs from petroleum and other energy prices; and ▪ the impact of price volatility and price inflation of foodstuffs on the national, regional, and/or household welfare level, as nationally determined
11. Change in income	Contribution of the following to change in income due to bioenergy production: ▪ wages paid for employment in the bioenergy sector in relation to comparable sectors ▪ net income from the sale, barter and/or own consumption of bioenergy products, including feedstocks, by self-employed households/individuals
12. Jobs in the bioenergy sector	▪ Net job creation as a result of bioenergy production and use, total and disaggregated (if possible) as follows: o skilled/unskilled o temporary/indefinite ▪ Total number of jobs in the bioenergy sector and percentage adhering to nationally recognized labour standards consistent with the principles enumerated in the ILO Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors
13. Change in unpaid time spent by women and children collecting biomass	Change in average unpaid time spent by women and children collecting biomass as a result of switching from traditional use of biomass to modern bioenergy services
14. Bioenergy used to expand access to modern energy services	▪ Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of energy and numbers of households and businesses ▪ Total number and percentage of households and businesses using bioenergy, disaggregated into modern bioenergy and traditional use of biomass
15. Change in mortality and burden of disease attributable to indoor smoke	Change in mortality and burden of disease attributable to indoor smoke from solid fuel use, and changes in these as a result of the increased deployment of modern bioenergy services, including improved biomass-based cookstoves
16. Incidence of occupational injury, illness and fatalities	Incidences of occupational injury, illness and fatalities in the production of bioenergy in relation to comparable sectors

ECONOMIC PILLAR	
THEMES The GBEP considers the following themes relevant, and these guided the development of indicators under this pillar: resource availability and use efficiencies in bioenergy production, conversion, distribution and end-use; economic development; economic viability and competitiveness of bioenergy; access to technology and technological capabilities; energy security/diversification of sources and supply; energy security / infrastructure and logistics for distribution and use.	
INDICATOR NAME	INDICATOR DESCRIPTION
17. Productivity	▪ Productivity of bioenergy feedstocks by feedstock or by farm/plantation ▪ Processing efficiencies by technology and feedstock ▪ Amount of bioenergy end product by mass, volume or energy content per hectare per year ▪ Production cost per unit of bioenergy
18. Net energy balance	Energy ratio of the bioenergy value chain with comparison with other energy sources, including energy ratios of feedstock production, processing of feedstock into bioenergy, bioenergy use; and/or life cycle analysis
19. Gross value added	Gross value added per unit of bioenergy produced and as a percentage of gross domestic product
20. Change in the consumption of fossil fuels and traditional use of biomass	▪ Substitution of fossil fuels with domestic bioenergy measured by energy content and in annual savings of convertible currency from reduced purchases of fossil fuels ▪ Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content
21. Training and re-qualification of the workforce	Percentage of trained workers in the bioenergy sector out of total bioenergy workforce, and percentage of re-qualified workers out of the total number of jobs lost in the bioenergy sector
22. Energy diversity	Change in diversity of total primary energy supply due to bioenergy
23. Infrastructure and logistics for distribution of bioenergy	Number and capacity of routes for critical distribution systems, along with an assessment of the proportion of the bioenergy associated with each
24. Capacity and flexibility of use of bioenergy	▪ Ratio of capacity for using bioenergy compared with actual use for each significant utilization route ▪ Ratio of flexible capacity which can use either bioenergy or other fuel sources to total capacity

Source: FAO 2011

1.2 Implementation of the GBEP indicators in different countries

As of mid-2019, the GBEP indicators have been implemented in a number of countries (Argentina, Colombia, Egypt, Germany, Ghana, Indonesia, Italy, Jamaica, Japan, the Netherlands, Paraguay and Vietnam), with Germany implementing the indicators for a second time and four other countries in the process of implementing them (Brazil, Uruguay, Ethiopia and Kenya). Trainings on the GBEP indicators were also organized in Togo, Ghana and the Philippines.

In each application, countries collected information regarding the performance of their bioenergy sector. The application of the indicators also provided national institutions with an understanding of what is needed to establish long-term monitoring of their bioenergy sectors. Improved knowledge and understanding of particular bioenergy pathways are one outcome. The other is an increased understanding of how to evaluate the contribution of the agriculture and energy sectors to national sustainable development priorities.

With regard to Ethiopia and Kenya, biomass use is very high in both countries. Overall energy demand is also rising in both countries due primarily to rapid economic growth (REN21 2016). This use, coupled with growth, has serious implications for the bioenergy sector, particularly as no

bioenergy sustainability framework currently exists in either country. Sustainably managing the bioenergy sector is central to each country's aspirations to achieve middle-income status by 2025 (Ethiopia) or 2030 (Kenya). However, policy makers are unable to make well-informed decisions to increase the sustainability of the bioenergy due to a lack of capacity.

1.3 Application of GBEP indicators in Kenya

The objective of applying the GBEP Sustainability Indicators for Bioenergy in Kenya was to help strengthen the country's capacity to monitor the environmental, social and economic impacts of the bioenergy sector. Results from the project can also be used to inform the design of effective sustainable bioenergy policies as part of low-carbon development strategies.

The first phase of the project assessed the priority bioenergy pathways to examine in Kenya. Building on a multi-stakeholder meeting in April 2018, two priority bioenergy pathways were identified. They were chosen based on their spread, their relevance in terms of policymaking, and the need for further evidence and analysis regarding their sustainability. The following pathways and the related sustainability issues represented the main focus of the project:[1]

1) Use of sugarcane bagasse briquettes in the tea industry; and
2) Household use of charcoal produced on woodlands and farmlands.

The application of the GBEP indicators was entrusted to a team of experts from the Stockholm Environment Institute (SEI), Kenya Forestry Research Institute (KEFRI), Strathmore University and the World Agroforestry Centre (ICRAF), coordinated by SEI. The team was supported by UNEP throughout the project, which provided technical support to the national experts on the meaning of and rationale behind the indicators and their indicative methodological approaches; on how to adapt the indicators to the country context; and on how to implement the chosen methodologies. This was done throughout the project in an iterative process.

Out of the April 2018 meeting, a multi-stakeholder working group (MSWG) was formed bringing together relevant stakeholders from the public and private sectors, including government agencies and academic and research institutions. The MSWG was consulted over the course of the project to validate data and discuss results and recommendations.

1.4 Outcome

The results and recommendations emerging from the application of the GBEP Sustainability Indicators for Bioenergy in Kenya were shared with stakeholder and national representatives during the final workshop, held on 5 November 2019 in Nairobi. The work behind these results and recommendations are detailed in the following sections.

This work is a starting point for increasing the sustainability of the bioenergy sector in Kenya. By establishing benchmarks, it is hoped the national government will continue to engage in a regular process of assessing the evolution of the sector. Through continuous reporting, results from the indicator calculations will help to inform decision makers as to the direction of national bioenergy policies with the ultimate goal of achieving sustainability of the nation's bioenergy sector.

[1] For a detailed description of the selected pathways in Kenya, see section 3.

1.5 References

Food and Agriculture Organization of the United Nations (2011). *The Global Bioenergy Partnership Sustainability Indicators for Bioenergy.* First Edition. http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf.

International Institute for Sustainability Analysis and Strategy (IINAS) and Institute of Energy and Environmental Research (IFEU) (2018). *Linkages between the Sustainable Development Goals (SDGs) and the GBEP Sustainability Indicators for Bioenergy (GSI): Technical Paper for the GBEP Task Force on Sustainability.* http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/IINAS_IFEU__2018__Linkages_SDGs_and_GSIs_-_final.pdf.

Renewable Energy Policy Network for the 21st Century (2016). *Eastern African Community Renewable Energy and Energy Efficiency Status Report.* Paris.

2 COUNTRY CONTEXT AND ENERGY OVERVIEW

2.1 Overview of Kenya

Kenya is located on the eastern part of the African continent. It lies across the equator at a latitude of 4° north to 4° south and a longitude of 34° east to 41° east. It contains a total area of 582,650 square kilometres (km^2) including 13,400 km^2 of inland water and a 536-kilometre coastline.

Kenya is divided into seven agro-ecological zones ranging from humid to very arid. Less than 20 per cent of the land is suitable for cultivation, of which only 12 per cent is classified as high potential (adequate rainfall) agricultural land and about 8 per cent is medium potential land. The rest of the land is arid or semi-arid. Only 60 per cent of the high potential land is devoted for crop farming and intensive livestock production, while the rest is used for food and cash crop production, leaving the remainder for grazing and as protected land. The most important environmental issues include water pollution from urban and industrial wastes; degradation of water quality from increased use of pesticides and fertilizers; water hyacinth infestation in Lake Victoria; deforestation; soil erosion; desertification; and wildlife poaching for game meat and animal trophies (Diaz-Chavez 2015).

Kenya, with a population of around 48 million people (urban population 10,183 and rural population 34,416), is the fourth largest economy on the African continent. The country's gross domestic product in 2018 was $88 billion, or $1,202 per capita. By sector, agriculture accounted for 34.5 per cent of GDP, industry for 17.8 per cent, and services for 47.5 per cent (CIA 2019).

The main products produced and exported include tea, coffee, sugar cane and horticultural products. The industrial sector includes the production of small-scale consumer goods (plastic, furniture, batteries, textiles, soap, cigarettes, flour), the processing of agricultural products, oil refining, cement and tourism.

2.2 Forestry

Kenya has 56.9 million hectares of land area of which 3.47 million hectares are covered with forests, equivalent to 5.6 per cent of the country (FAO 2010). The country has a low deforestation rate and has reduced this rate from 0.35 per cent in 1990 to 0.31 per cent for the period 2005-2010 (FAO 2010). The most immediate threats to Kenya's forests are linked to the country's rapid population growth, agricultural expansion, unsustainable wood utilization levels, high energy demand and over-grazing (REDDdesk 2015.)

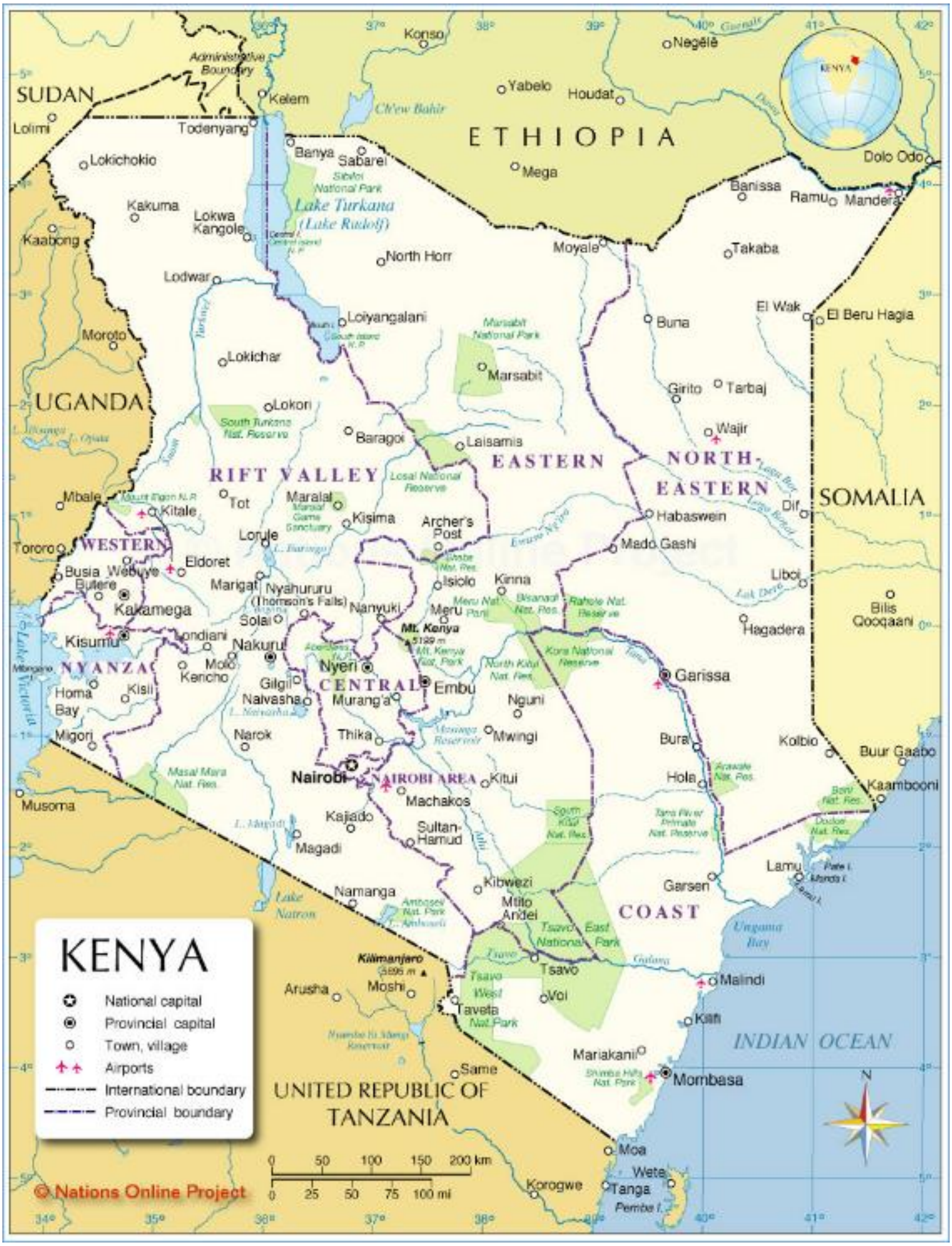
Four woody biomass products dominate the Kenyan market: timber, poles, firewood and charcoal (Table 2.1). These products were evaluated to assess the technical energy potential considering sawdust and off-cuts and chips; the technical potential of woody biomass residues is 6 petajoules of sawdust and 19 petajoules of off-cuts and chips.

Table 2.1. Woody biomass products in Kenya, 2013

	Timber	Poles	Firewood	Charcoal	Total
	(million m^3)				
Supply potential	7.36	3.03	13.65	7.36	31.40
Available supply	2.40	2.88	12.97	1.18	19.43
Lost volumes	4.96	0.15	0.68	6.18	11.97
Percentage loss	0.676	0.05	0.05	0.84	N/A

Source: Dardamanis et al. 2015

Map 2.1. Kenya

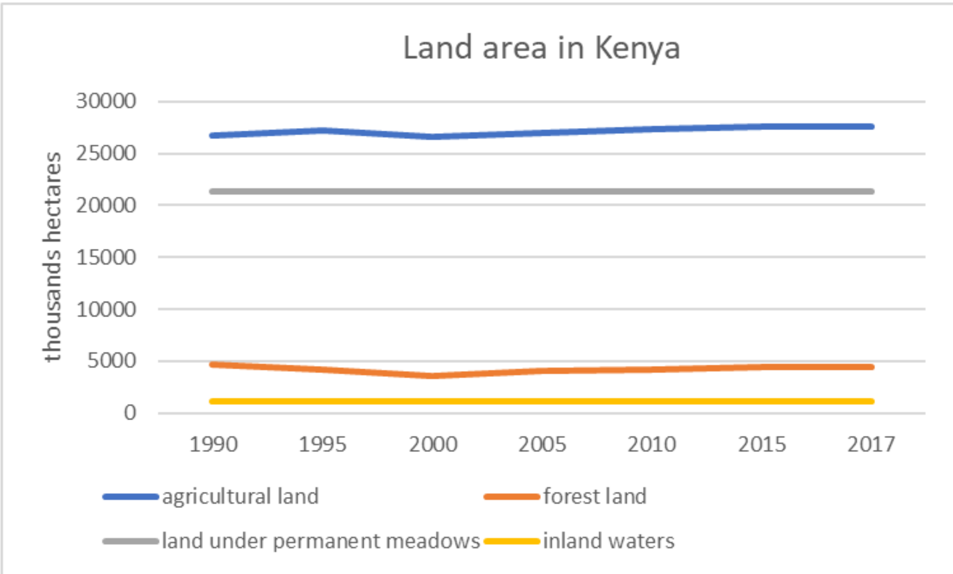


Source: Nations Online Project 2019

The Kenyan Forest Service reported increased importation of timber from the Democratic Republic of the Congo and from Angola's Cabinda area due to the construction boom in Nairobi (UNEP 2012). There is also increasing demand for firewood from tea factories and for electricity transmission poles. Regarding this timber shortage, the business of growing eucalyptus in Kenya has been proposed as the best option for enhancing domestic supply, since investment costs are low compared to other cash crops. Reports indicate that growing eucalyptus is a profitable business in Kenya and that farmers would be willing to plant trees on their fallow land (UNEP 2012).

Forest cover has declined in the last 10 years and arable land has increased. Only 8 per cent of arable land and 75 per cent of Kenya's workforce are engaged in agriculture, and Kenyan farmers face growing problems of soil erosion, deforestation, water pollution, and desertification (FSD 2015). The drought of 2006 left 3.5 million people with barely enough food to survive, and in the north of the country the drought affected pastoralism and created wider conflicts over water (FSD 2015).

Figure 2.1. Land use area in Kenya



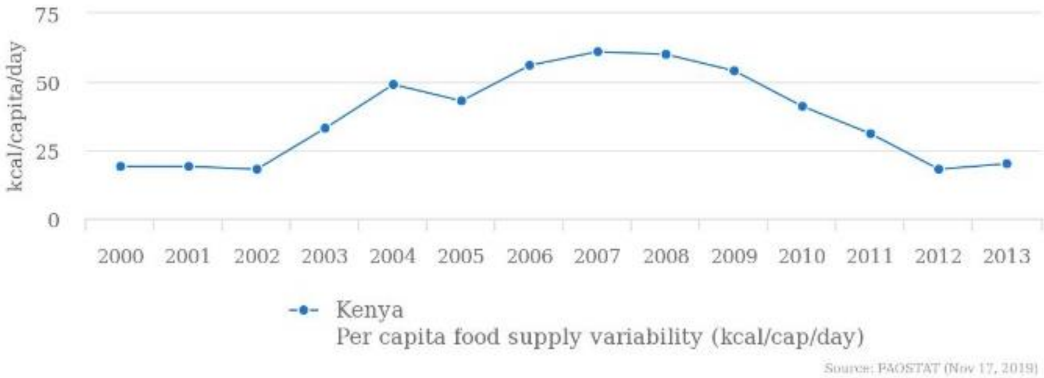
Source: FAOSTAT 2019

2.3 Food security

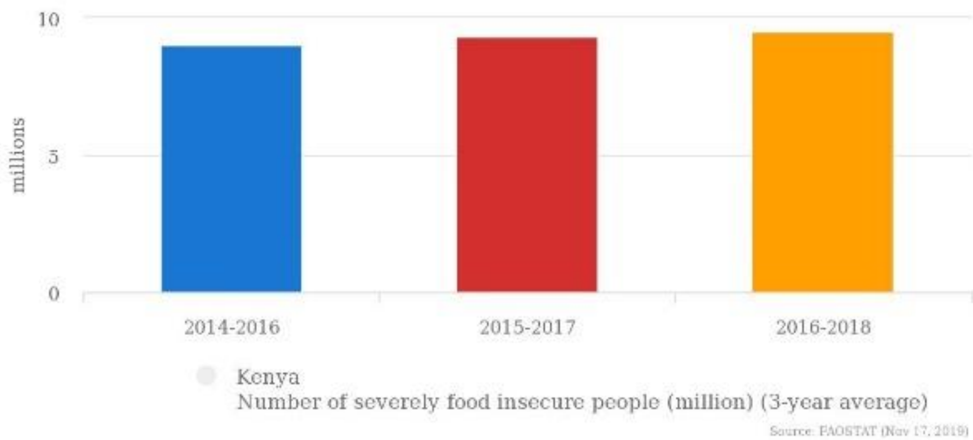
The number of acutely food insecure people in Kenya is stable at around 1.6 million, mainly concentrated in pastoral and marginal agricultural areas. Food security of poor households is of particular concern in south-eastern and coastal areas that harvested well-below-average "short-rainy" season crop production at the beginning of the year. The per capita food supply has increased in the last 20 years and the undernutrition status has decreased (Figure 2.2). Nevertheless, imports of maize from neighbouring countries are still constant, and food security is associated with weather conditions (rainfall) for domestic production (FAOSTAT 2019).

A report from UNEP (2012) indicated that fostering sustainable biomass production in Kenya will have a positive impact on local employment and income generation. The forest industry is still based on traditional, labour-intensive production techniques, particularly in firewood and charcoal production, and therefore will benefit from technological improvement. The charcoal industry employed nearly 700,000 people in 2010, supporting around 2.5 million family members. This industry provides high labour stimulus in rural and poorer areas, and expanding the number of wood fuel plantations would provide even more local employment (UNEP 2012). Eucalyptus plantations are expected to increase in the future.

Figure 2.2. Food security data for Kenya



A. Per capita food supply variability



B. Number of severely food insecure people (3-year average)

Source: FAOSTAT 2019

2.4 Energy sector

Energy sources

Kenya has a high and diversified potential of renewable energy with abundant solar, hydro, wind, biomass and geothermal resources. There are coal deposits in eastern Kenya; however, due to envisaged social and environmental impacts, mining has not been carried out. Some petroleum exploration and mining exists in Turkana, and natural gas deposits have been discovered in Lamu.

Electricity

Kenya has an installed capacity of 2,819 megawatts (MW) of electrical power (Table 2.2), including a recently installed capacity of 310 MW of wind in 2019. Geothermal and hydropower generate more than 70 per cent of total electricity consumed in the country. In 2018, only around 56 per cent of the population had access to electricity.

Table 2.2. Installed power capacity and generation in Kenya, as of October 2019

Source	Capacity (MW)	Capacity (%)
Geothermal	828	29.4%
Hydropower	826	29.3%
Fossil fuels (including natural gas, diesel and emergency power)	720	25.5%
Wind	335	11.9%
Solar	50	1.8%
Bagasse cogeneration	28	1.0%
Others	32	1.1%
Total	2 819	100.0%

Source: Wikipedia 2019

Energy balance

The main source of primary energy in Kenya is biomass (wood fuel), which accounted for around 68 per cent of all energy consumed in 2017, and for 90 per cent of rural household energy needs. The main sources of biomass for cooking and heating energy are charcoal, fuelwood and agricultural waste. The rest is supplied by petroleum (25 per cent) and electricity (4 per cent) (Table 2.3). For household energy, electricity is used mainly for lighting, and a significant share of the electricity (over 60 per cent) is produced from hydropower (EEP 2015). Kenya was recently ranked the world's eighth largest geothermal producer.

Bioenergy and biomass

Biomass contributes a large share of Kenya's final energy demand, supplying more than 90 per cent of rural household energy needs. The main sources of biomass in the country are charcoal, wood fuel and agricultural waste. Sustainability of the bioenergy sector is central to Kenya's aspirations to achieve middle-income status by 2030 and to contribute to the Paris Agreement, as indicated in the country's Nationally Determined Contribution (NDC) as well as the Climate Change Act (2016).

The government has identified substantial potential for power generation using forestry and agro-industry residues, including sugarcane bagasse. The total potential for cogeneration using bagasse is 193 MW. Opportunities within other sugar factories are estimated to reach 300 MW but have not been exploited. Other bioenergy uses in Kenya include biogas, fuelwood, briquettes, pellets and charcoal. The full potential to achieve sustainable biomass production in the country is still under development.

Biomass is faced with the challenge of competing with other areas of interest such as land use, forestry and agriculture. The Government of Kenya is looking for ways to discourage deforestation, which has resulted from the rising demand for fuelwood because of the rapidly growing population. Through the Ministry of Energy, the government is working on a framework to shift from traditional to modern biomass technologies. The extraction rate of biomass is higher than the natural growth of forests, making biomass a non-renewable energy source (EEP 2015).

More details on the potential of agriculture residues are provided in chapter 3.

Table 2.3. Kenyan energy balance for 2017

	Coal [1]	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Wind, solar, etc.	Biofuels and waste	Electricity	Heat	Total [2]
	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Production						276	4 143	17 281			21 700
Imports	463	780	4 850						15		6 107
Exports			-26						-2		-28
International marine bunkers [3]			-45								-45
International aviation bunkers [4]			-692								-692
Stock changes											
Total primary energy supply	463	780	4 086			276	4 143	17 281	13		27 042
Transfers											
Statistical differences			62						24		86
Electricity plants			-600			-276	-4 143	-36	888		-4 168
Combined heat and power plants											
Heat plants											
Gas works											
Oil refineries		-780	750								-30
Coal transformation											
Liquefaction plants											
Other transformation								-5 761			-5 761
Energy industry own use			-39						-4		-43
Losses									-193		-193
Total final consumption	463		4 259					11 484	727		16 934
Industry	463		640						374		1 476
Transport			2 886								2 886

Residential			506					11 484	248		12 239
Commercial and public services									105		105
Agriculture / forestry			48								48
Fishing											
Non-specified			55								55
Non-energy use			124								124

(1) The column of coal also includes peat and oil shale where relevant.
(2) Totals may not add up due to rounding.
(3) International marine bunkers are included in transport for world totals.
(4) International aviation bunkers are included in transport for world totals

Source: IEA 2019

2.5 Policy framework

Kenya’s main strategic document is Kenya Vision 2030, which provides the long-term development blueprint for the country and aspirational goals for a better society by the year 2030. The main aim of the Vision is to create “a globally competitive and prosperous country with a high quality of life by 2030”. It aims to transform Kenya into “a newly-industrialising, middle income country providing a high quality of life to all its citizens in a clean and secure environment" (Kenya Vision 2030 2019). The “Big 4 Agenda” of the government focuses on the development of four pillars of the economy: food security and nutrition, affordable universal health care, affordable housing and enhancing manufacturing.

Kenya has numerous policies related to the energy sector, agriculture and forestry. These include the National Energy Policy 2015, Energy Act 2019, Agriculture Act 2012, National Forest Policy 2014, Land Policy 2009 and National Environmental Policy (NEP) 2012.

With regard to climate change, Kenya is a signatory of the Paris Agreement. The Climate Change Act (CCA) of 2016 provides a framework for promoting climate-resilient, low-carbon economic development. The first National Climate Change Action Plan (NCCAP) covered the period 2013-2017, and the second NCCAP covers the period 2018-2022. The NCCAP presents Kenya’s low-carbon development pathway options and addresses finance, policy and legislation, knowledge management, capacity development, technology requirements and monitoring and reporting for pathway options.

The National Adaptation Plan 2015-2030 aims to enhance Kenya’s climate resilience towards the achievement of Vision 2030. In its National Determined Contribution, Kenya targets a 30 per cent reduction in economy-wide greenhouse gas emissions by 2030 compared to a business-as-usual scenario of 143 million tons of carbon dioxide-equivalent ($MtCO_2e$), conditional to the level of international support. Kenya has several institutions to enforce and act on these plans and strategies. Among them, the Climate Change Directorate under the Ministry of Environment and Natural Resources acts as focal point for the United Nations Framework Convention on Climate Change.

2.6 References

Central Intelligence Agency (2019). The World Factbook. The World Factbook. gov. Accessed June 2019.

Dardamanis, A., Mai-Moulin, T. and Junginger, M. (2015). *Biomass Use and Potential for Export to the European Union from 2015 to 2030. Kenya.* Deliverable 3.1 Biotrade2020+. Intelligent Energy funded project.

Diaz-Chavez, R. (2015). *Availability and Sustainable Potentials. Biomass Use and Potential for Export to the European Union from 2015 to 2030.* Kenya. Deliverable 2.1 Biotrade2020+. Intelligent Energy funded project.

Energy and Environment Partnership (2015). Kenya. http://eepafrica.org/projects/kenya/. Accessed February 2015.

FAOSTAT (2019). Kenya statistics. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#country/114. Accessed September 2019.

Food and Agriculture Organization of the United Nations (2010). *Global Forest Resources Assessment Country Report Kenya*. http://www.fao.org/forestry/20360-0381a9322cbc456bb05cfc9b6a7141cdf.pdf. Accessed March 2015.

Foundation for Sustainable Development (2015). Kenya: Environmental issues. http://www.fsdinternational.org/country/kenya/envissues. Accessed May 2015.

International Energy Agency (2019). World Energy Balances. https://www.iea.org/statistics/?country=KEN&isISO=true (accessed 1 December 2019).

Kenya Vision 2030 (2019). https://vision2030.go.ke/

Nations Online Project (2019). http://www.nationsonline.org/oneworld/map/kenya_map.htm.

REDDdesk (2015). REDD in Kenya. http://theredddesk.org/countries/kenya. Accessed March 2015.

United Nations Environment Programme (2012). *The Role of Forest for the Kenyan Economy*. http://www.unep.org/dewa/Portals/67/pdf/Kenya_InputOutput.pdf. Accessed March 2015.

Wikipedia (2019). Energy in Kenya. https://en.wikipedia.org/wiki/Energy_in_Kenya#Sources_of_electricity.

3 DESCRIPTION OF THE SELECTED BIOENERGY PATHWAYS

The sustainability indicators were applied to two bioenergy pathways selected in consultation with stakeholders. The data were assessed from both primary and secondary sources, particularly from field visits to bioenergy producers and users, such as briquette companies, tea factories, county governments, and charcoal producers and distributors. The indicators that were applied to the two pathways were assessed and validated with stakeholders.

The two pathways selected were:

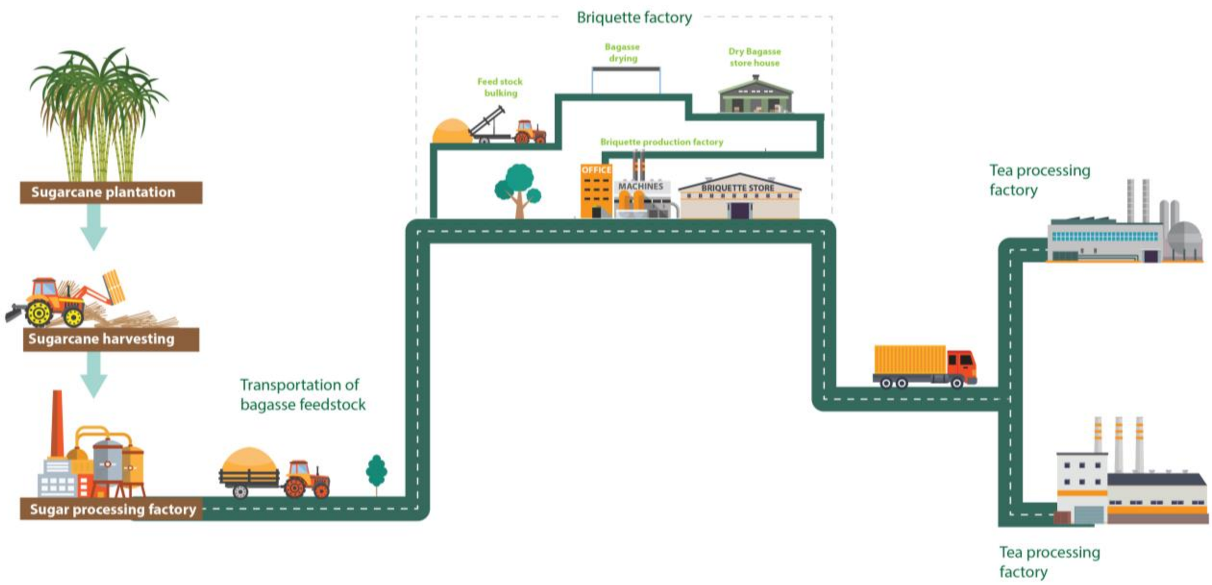
- Use of sugarcane bagasse briquettes in the tea industry.
- Household use of charcoal produced on woodlands and farmlands .

3.1 Use of sugarcane bagasse briquettes in the tea industry

3.1.1 Introduction

This bioenergy pathway focuses on the use of sugarcane bagasse briquettes by the tea industry in Kenya as an alternative to firewood. The demand for firewood for use in the tea industry is around 1 million tons of firewood per year (AFA-TD 2019). This massive demand for firewood by the industry contributes to deforestation. This calls for greater use of alternative thermal bioenergy sources such as briquettes from agricultural residues, as illustrated in Figure 3.1.

Figure 3.1. The value chain for production of sugarcane bagasse briquettes and use by the tea industry



3.1.2 Agriculture residues

Kenya has potential to produce bioenergy from a variety of biomass feedstock resources, including forest and agricultural residues, energy crops and the organic component of municipal solid waste. The existing amount of agricultural residue presents a huge untapped potential for clean modern energy in the country.

Table 3.1. shows the top 10 agricultural commodities in Kenya by volume of production, according to the FAOSTAT (2019). Several crops were identified as having the potential to produce enough residues to be used for energy purposes, including for export to the European Union (EU) (Table 3.2.).

Table 3.1. Top 10 commodities in Kenya

	Commodity	Quantity (tons)
1	Sugar cane	4 751 609
2	Milk, whole fresh cow	3 560 702
3	Maize	3 186 000
4	Potatoes	1 519 870
5	Cassava	1 112 000
6	Milk, whole fresh camel	876 224
7	Beans, dry	846 000
8	Mangoes, mangosteens, guavas	772 680
9	Bananas	742 000
10	Cabbages and other brassicas	690 622

Source: FAOSTAT 2019

Table 3.2. Technical potential of residues of selected crops in Kenya

Agricultural products	Technical potential of residues in mass and energy					
	Field (thousand tons)	Process (thousand tons)	Total (thousand tons)	Field (petajoules)	Process (petajoules)	Total (petajoules)
Maize	10 037	6 026	16 063	125	93	218
Mangoes	5 562	0	5 564	89	0	89
Bananas	2 649	0	2 649	42	0	42
Sugarcane	1 165	1 252	2 416	19	16	35
Potatoes	1 050	0	1 050	18	0	18
Beans	1 123	0	1 122	18	0	18
Coffee	0	1 029	1 029	0	13	13
Sisal	131	669	800	2	10	12
Wheat	654	0	654	11	0	11
Cassava	518	0	518	9	0	9

Source: Dardamanis et al. 2015

Most of the crops are semi-processed, and what remains as waste in the form of husks, cobs, shells, bagasse or straw can be used for other purposes such as for an energy source / production, fodder, composting and mulching, among other uses.

As of 2013, a total of 3 million cubic metres (m^3) of agricultural residues were produced in Kenya. Most of these wastes have been used as fodder for animals, as waste material for composting manure and as biomass energy, but at low levels. The rest of the residues are burned or disposed of in the open environment, a major cause of environmental pollution. Specific uses of these agricultural residues include:

- Coffee husks: mainly used internally by coffee processing plants for heating industrial boilers; mulching in farms; and informal briquette production.
- Maize cobs: frequently used in cooking ovens and as animal feed in farm households.
- Coconut shells: frequently used for cooking and for jewelry making and basketry.
- Sugarcane bagasse: frequently used internally by sugar mills for heating boilers (Table 3.3); as animal feed; and for production of chipboards and briquettes.

Table 3.3. Sugarcane bagasse feedstock production in Kenya, 2013-2017

	Tons of bagasse				
Sugar factory	**2013**	**2014**	**2015**	**2016**	**2017**
Chemelil	115 391	192 939	159 289	112 922	84 625
Muhoroni	149 914	201 625	158 403	133 060	124 444
Mumias	696 525	539 116	511 902	395 343	109 642
Nzoia	286 439	263 671	266 143	305 921	154 213
South Nyanza (Sony)	239 439	224 785	264 974	262 029	163 121
West Kenya	341 687	295 690	410 869	326 935	305 800
Soin	7 500	3 293	-	-	-
Kibos	251 125	192 815	350 088	338 320	254 125
Butali	141 760	200 103	182 273	330 862	182 097
Transmara	129 705	177 023	178 687	282 105	138 800
Sukari Industries	108 853	131 838	126 148	166 330	118 151
Kwale International	-	-	-	114 720	70 130
Total bagasse produced	**2 468 338**	**2 422 898**	**2 608 776**	**2 768 548**	**1 705 148**

Source: AFA-SD 2017

3.1.3 Briquette production and consumption

Briquette production

Kenya's total potential for production of briquettes using agricultural waste, especially sugarcane bagasse, is huge and remains largely untapped. According to the Sugar Directorate, around 2.4 million tons of bagasse generated by the country's 12 sugar mills is unutilized (AFA-SD 2017). As illustrated in Figure 3.1, production of the briquettes begins with the collection of the agricultural residues from millers and farmers. The feedstock is then dried either in the open air or in industrial rotary systems at high temperatures, to less than 15 per cent moisture content. Then, it is compressed at high pressure to form briquettes.

According to the Kenya Briquette Industry Study (GVEP 2010), briquettes produced from agricultural and forest residues such as bagasse, coffee, maize and saw dust provide a more sustainable alternative to firewood and charcoal. The process involves production of briquettes using carbonized or non-carbonized biomass raw materials. The technology used depends on the production scale, ranging from informal operations to large industrial operations.

Steps in briquette production

Activities in the briquette production chain begin with the bagasse acquisition stage, and the following income-generating activities can be considered:

1) Bagasse transport from the sugar factory to the briquetting factory
2) Bagasse drying
3) Briquetting
4) Briquette transport from the briquetting factory to the tea factory
5) Briquette reception and storage at the tea factory
6) Boiler feeding and operation.

Details are provided in the indicator analysis.

Briquette consumption

The briquetting industry in Kenya is picking up rapidly as a potential source of livelihood as well as fuel for industrial, institutional and domestic use. The number of enterprises in the briquette value chain is increasing as more consumers become aware of the product.

Major consumers of non-carbonized briquettes include the tea industry, schools and hospitals, tobacco industries and vegetable oil processing industries, among others. A number of enterprises are carrying out commercial production of non-carbonized briquettes for industrial and institutional use, such as Biofuel Kenya Company, Transmara Sugar Company Ltd, BAT Kenya Ltd; Karani Biofuel Ltd, Tamua Ltd and White Coal, among others. The potential application of non-carbonized briquettes remains untapped due to policy, market and technology barriers.

The use of non-carbonized briquettes by tea factories is increasing rapidly in areas with abundant biomass for briquette production. In the sugar-belt region of western Kenya, where large amounts of sugarcane bagasse remain unutilized, a number of industries have emerged to supply the needed bioenergy source.

The total annual production level of briquettes in Kenya is not well known since the sector is very new. According to the briquette companies contacted during the field visits for this study, the approximate production capacity of producers is 45,000 tons/year (5 tons/day for 300 days/year) per company. Currently around 30 companies produce non-carbonized briquettes in Kenya, using sugarcane bagasse, rice husks, pineapple waste, etc. KEFRI is planning a nationwide survey on the topic in 2020.

3.1.4 The tea industries

Kenya is the world's third largest producer and exporter of tea, with annual production of around 470 million kilograms and annual export earnings of 140 million Kenyan shillings (KSh) while supporting the livelihoods of around 3 million families. Currently, there are 113 tea factories in Kenya. Almost 99 per cent of the thermal energy that is used in these factories for withering and drying green tea leaves comes from firewood and other biomass sources, while the remaining 1 per cent is from fuel oil.

In Kenya, the tea industry is among the major consumers of bioenergy, especially in the green-leaf production process. According to the AFA-Tea Directorate, in 2018, the tea factories in operation consumed around 904,000 tons of firewood, accounting for around 4.4 per cent by volume of firewood consumption per year in Kenya (AFA-TD 2019). In addition to firewood, a number of tea industries use alternative biomass sources such as non-carbonized biomass briquettes for energy. For example, in the tea highlands of western and central Kenya, briquette factories are supplying the tea factories with non-carbonized briquettes for their boiler operations.

Tea factories in Kenya are energy-intensive operations that require constant monitoring to ensure minimum wastage of energy. Recently, however, a number of tea factories have developed and adopted working energy policies that aim to ensure energy efficiency in the sector. To manage the cost of thermal energy and reduce the cost of production, a number of tea factories are engaged in energy initiatives, mainly upscaling of the wood fuel programme and the use of alternative sources of energy, which include briquettes.

Table 3.4. Production capacities and bioenergy used in Kenya's tea factories, 2014-2018

	2014	2015	2016	2017	2018
Number of tea factories	104	104	107	108	113
Green leaf processed (kg)	1 869 439 883	1 676 687 741	1 986 647 561	1 847 402 504	2 070 594 637
Processed tea produced (kg)	445 104 734	399 211 367	473 011 324	439 857 739	492 998 723
Firewood used (m^3)	1 483 682	1 330 704	1 576 704	1 466 192	1 643 329
Bone-dry firewood used (tons)	816 025.35	731 887.51	867 187.43	806 405.85	903 830.99

Source: AFA-TD 2019

3.1.5 A case-study approach

A case-study approach was adopted for this project. Three briquette factories were visited; two in Kisumu, the sugarcane belt, and one in Thika. Three tea companies were also visited, in Vihiga, Kisii and Murang'a, in agreement with the Kenya Tea Development Agency. The indicators applied to these cases do not necessarily reflect all the sector.

3.2 Household use of charcoal produced on woodlands and farmlands

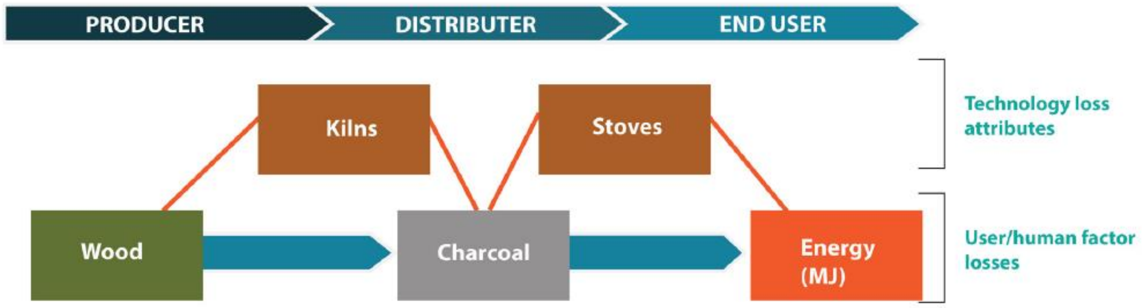
3.2.1 Introduction

In Kenya, 42 per cent of urban households and 40 per cent of rural households use charcoal (Ministry of Energy and Clean Cooking Alliance, 2019). This represents a decline from the 82 per cent of urban households and 34 per cent of rural households that used charcoal as reported in 2002 (MoE 2002). This decline could be attributed to the logging/charcoal ban in effect as of February 2018, which coincided with this study undertaken late 2018. Charcoal is also a major source of energy for small and medium enterprises such as poultry farming, bakeries and eateries.

Kenya's charcoal industry is valued at KSh 135 billion ($1.35 billion) (MEWNR 2013a). The contribution to the economy has increased fourfold since 2005 (KSh 32 billion) and eightfold since 2002 (KSh 17 billion) (MEWNR 2013a; Mutimba and Barasa 2005; MoE 2002;). Demand for charcoal is increasing rapidly due to population growth, increased urbanization and the development of cottage industries. In 2013 Kenya had a reported charcoal supply potential of over 7,358,717 m^3 and a demand of 16,325,810 m^3; with a per capita consumption of 0.39 m^3, this left a deficit of 8,967,093 m^3 (55 per cent) (MEWNR 2013b). A 20-year prediction indicated a 10 per cent increase in supply and a 19 per cent increase in demand by the year 2032 (MEWNR 2013b).

Unsustainable charcoal production and inefficient use is associated with land degradation, deforestation and air pollution. Some of the main effects of land degradation and deforestation include erosion and flooding, lower carbon sequestration capacity and loss of habitat and biodiversity. Unsustainable and inefficient charcoal production accounts for the highest negative environmental impact in the charcoal value chain (production, transport and consumption) (Figure 3.2). Charcoal is produced in rural areas and used mainly in urban areas.

Figure 3.2. A simplified charcoal value chain schematic



Source: Transrisk 2018

3.2.2 Sources of wood for charcoal production

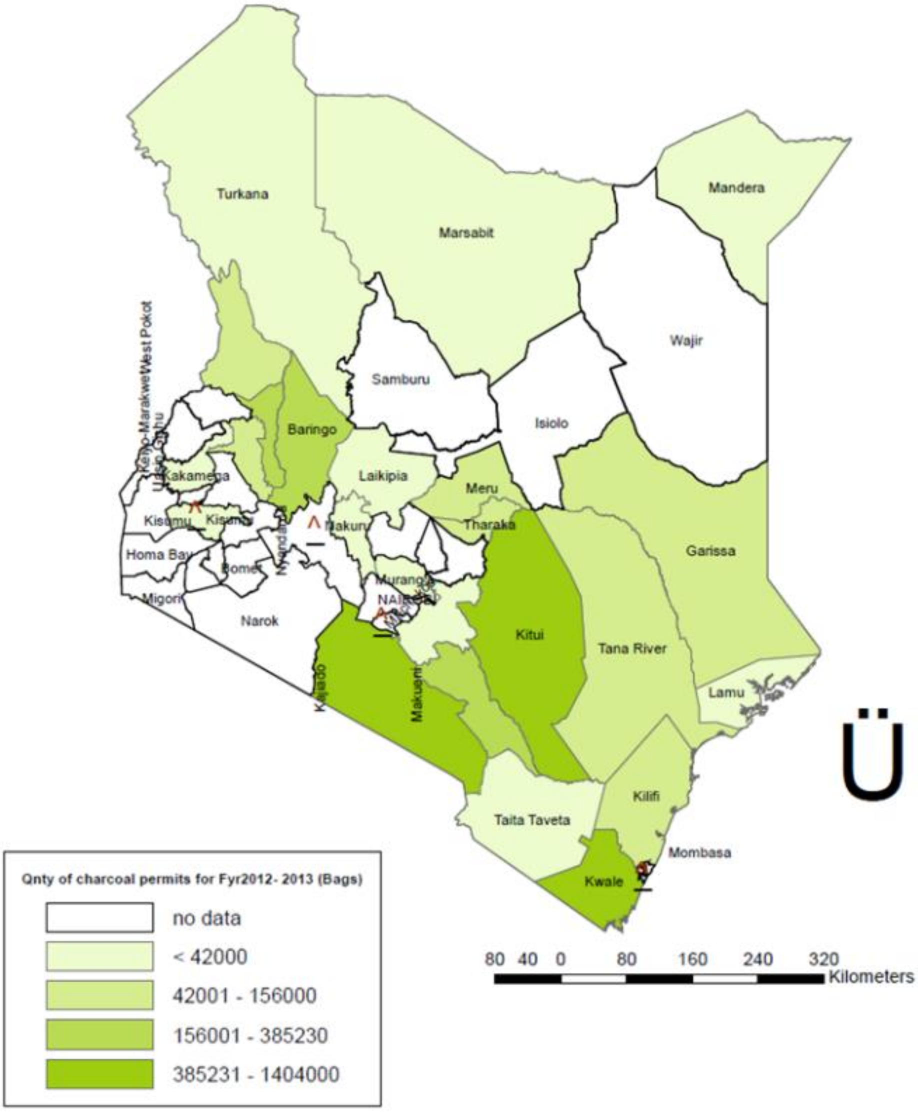
The main source of wood used for charcoal is trees on farmlands, mainly native woodlands (MEWNR 2013a). Mutimba and Barasa (2005) reported that charcoal is sourced from residents' own farms (44 per cent), private land (38 per cent), government or county council land (13 per cent) and communal land (5 per cent).

The preferred tree species for charcoal are: *Tarchonanthus camphoratus, Olea Africana,* Acacia species *(A. tortils, A. drepanolobium, A. polyacantha, A. mellifera, A. horkii, A. horida, A. xanthophloea and A. mearnsii),* Terminalia species *(T. brownie, T. spinosa) and Balanites aegtptiaca.* The criteria for selection of species used for charcoal production are shifting from quality of charcoal to availability, following degradation of the preferred species (MEWNR 2013a). Other opportunities for sourcing wood for charcoal are arising from the growth of invasive species such as *Prosopis juliflora* (Mathenge), which is being exploited through a management-by-use strategy (Mbaabu et al. 2019).

An estimated 2.5 million tons of charcoal are produced in the country annually, up 56 per cent from the 1.6 million tons estimated in 2005 (Mutimba and Barasa 2005; MEWRN 2013a). The number of charcoal producers has increased 27 per cent since 2005, to an estimated 253,808 (Mutimba and Barasa 2005; MEWRN 2013a). According to a national survey by the Ministry of Environment, Water and Natural Resources (2013a) the average amount of charcoal per producer is around 30 bags (50 kilograms each) per month.

In Kenya, charcoal is produced mainly from arid and semi-arid lands, which include the counties of Baringo, Elgeyo Marakwet, Garissa, Kajiado, Kilifi, Kitui, Kwale, Laikipia, Makueni, Mount Elgon, Narok, Nyandarua, Tana River, Tharaka Nithi and Turkana (Map 3.1) (MEWNR 2013a).

Map 3.1. Charcoal sources by county



Source: MEWNR 2013a

Bailis and Hyman (2011) reported that the charcoal consumed in Nairobi was mainly supplied by Narok (70 per cent), Ukambani (22 per cent) and Kajiado (4 per cent). The Ministry of Environment, Water and Natural Resources (2013a) also identified Ukambani-Kitui and Makueni counties as some of the major sources of charcoal for Nairobi. In Kitui and Makueni, charcoal production is frequently undertaken as a primary activity by households with few other income-generating opportunities and is usually a fallback during drought. Kajiado County seems to have overtaken Narok as a major supplier of charcoal to Nairobi, as most transporters interviewed indicated sourcing their charcoal from Kajiado. The study was, however, not able to quantify charcoal production within Narok County, due to the ongoing ban on production within the county.

3.2.3 Charcoal carbonization technologies

Traditional earth-mould kilns are the most prevalent conversion technologies, used by over 90 per cent of charcoal producers and with a yield efficiency of 10 per cent to 18 per cent (MEWNR 2013a). However, through research a number of improved technologies have been developed and are

increasingly being promoted (Oduor et al. 2012). These improved kilns with yield efficiency of around 30 per cent include: improved earth-mound kilns, the Casamance kiln, the drum kiln, portable metal kilns, the Brazilian masonry kilns and half orange. Despite increased awareness of these technologies, the rate of adoption remains low due to factors including the cost of the technology, expertise required, cultural preferences, unavailability and immobility of some of the kilns (Kitheka et al. 2017). Figure 3.3 shows some of the improved kilns being promoted in Kenya.

Figure 3.3. Improved earth kiln (A), portable kiln (B) and metal drum kilns (C)

Photos by ICRAF and KEFRI

3.2.4 Transport and marketing

According to the Ministry of Environment, Water and Natural Resources (2013a), there are over 1 million charcoal transporters and vendors in Kenya. There is no defined packaging for charcoal from the producer side. However, on average a bag of charcoal weighs around 35 kg. Charcoal packaging varies across regions depending on the availability of packing materials and means of transport. For example, in coastal and western regions, big gunny bags are prevalent, whereas in north-eastern Kenya, smaller bags are preferred.

Common means of transport range from large trucks covering long distances, to donkeys, oxcarts, motor vans, motorcycles and foot transport that are used to supply local markets. When considering Nairobi as a key consumer of charcoal, this resource is transported at distances between 150 kilometres and 500 kilometres, given that Baringo, Garissa, Kajiado, Kitui, Kwale, Makueni, Narok and Tana River are the main sources of charcoal used in Nairobi (MEWNR 2013a).

Charcoal is sold mainly in major markets / shopping centres, from kiosks and on the roadsides in production areas. It is sold either in 35 kilogram bags or from recycled containers such as 20-litre buckets and tins of 4 kg/litre or 2 kg/litre in volume of the initial product. Charcoal prices fluctuate with the season, with prices going up during the rainy season when production and local transport are affected by rains and higher involvement in farming activities. The prices also increase with charcoal bans. The unit price of charcoal increased by 118 per cent for producers and 178 per cent for retailers over the period 2005-2013 (Mutimba and Barasa 2005; MEWNR 2013a). These studies shows that average price per bag for producers rose from KSh 201 to KSh 438 and for retailers from KSh 700 to KSh 1,949.

3.2.5 Charcoal consumption

Charcoal consumption outpaced population growth in sub-Saharan Africa during 1961-2014 (Bailis et al. 2017). A survey in Kenya estimated that national charcoal consumption grew by 5 per cent per year during 2004-2013, which was higher than the rate of urbanization (Iiyama et al. 2014) and the overall rate of population growth (2.7 per cent) during the same period (Iiyama et al. 2014). The per capita consumption of charcoal is estimated at 0.391 m^3, which translates to around 81 kilograms per person per year (MEWNR 2013a). This is consistent with the recent findings of per capita annual

consumption of 79 kilograms (Ministry of Energy and Clean Cooking Alliance 2019) for a standard household of five people.

Around 85 per cent of household charcoal consumers used the improved charcoal stove called the Kenya Ceramic Jiko (KCJ), which is locally produced by artisans and has a clay liner (Mugo et al. 2007). The KCJ has a thermal efficiency of around 33-35 per cent compared to 10-15 per cent obtained in traditional stoves (Mugo et al. 2007). There are many types of improved charcoal stoves in the market. However, their adoption is still low due to the cost of the device and the persistence of traditional cooking culture. For example, while use of the KCJ is high, the use of branded improved stoves is low at 3.6 per cent in urban areas and 2.8 per cent in rural areas (MoE and CCA 2019). Some stoves, such as the KCJ, are made by artisans, while others are industrial produced and branded, such as the JikoKoa and Envirofit (Figure 3.4).

Figure 3.4. Kenya Ceramic Jiko (KCJ (A), JikoKoa by Burn Manufacturing (B) and Envirofit (C)

Photos by ICRAF and from stove companies

By 2013, the Kenya Country Action Plan estimated that 3.2 million households were accessing improved cookstoves. The Ministry of Energy and Petroleum and stakeholders have set a target to reach 5 million Kenyan households and institutions with improved cookstoves for cooking and heating applications by 2020 (CCA 2019).

3.2.6 Socio-economic issues and gender

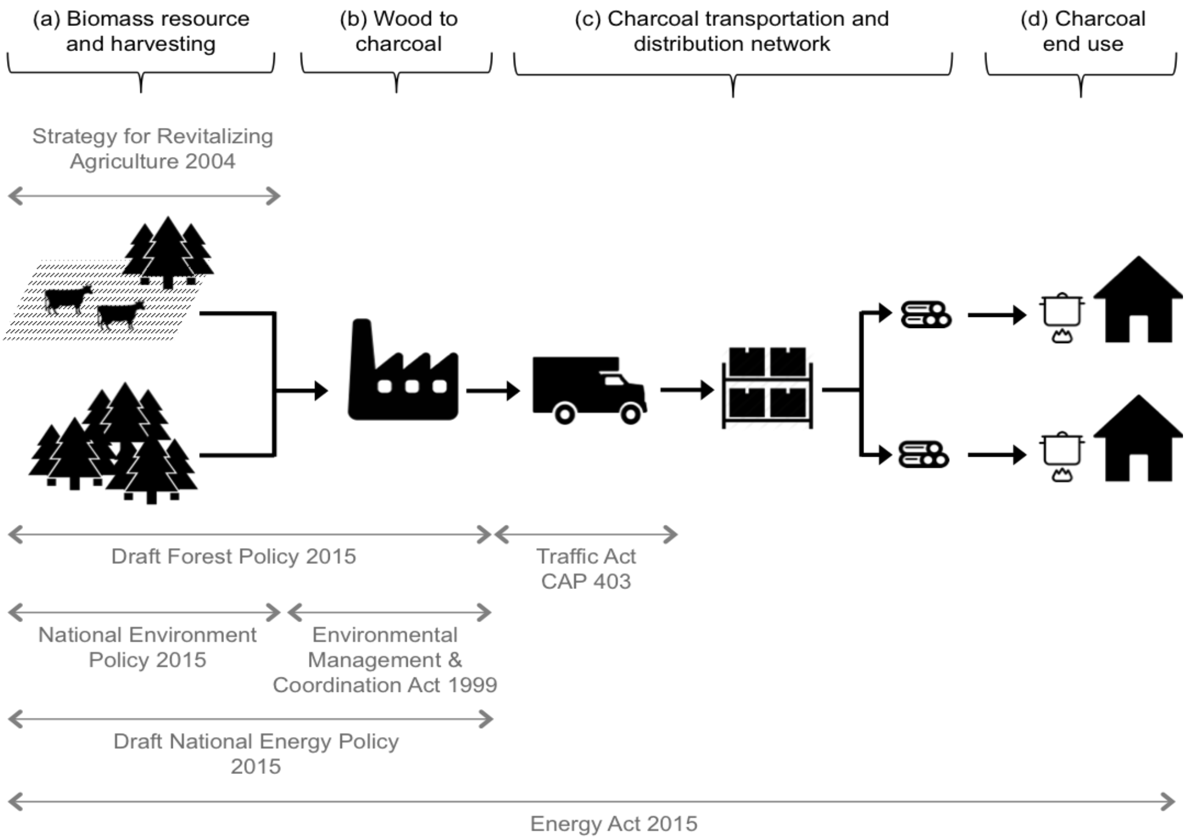
Although the charcoal sector supports 253,808 charcoal producers and provides KSh 135 billion to Kenya's economy, it is barely recognised in formal annual national economic reporting. Around 80 per cent of the charcoal income is shared equally among the vendors, police, buyer and transporters. Less than 20 per cent goes to the landowners and producers, while the government retains little or none from taxation (Bailis and Hyman 2011). The private sector, development partners and government are undertaking efforts in stove manufacturing, distribution, awareness-raising, financing and more to ensure a market-based approach in the cookstoves sector. The sector creates an estimated 3,000 direct local manufacturing jobs, with 300,000 stoves sold in a year.

The Clean Cooking Association of Kenya estimated that under the value-added tax zero-rated regime, cookstoves worth KSh 1.7 million would be sold from 2017 to 2020.

3.2.7 Policy framework

Charcoal is considered one of the most complex economic sectors, with various interactions among varied stakeholders with diverse interests (Figure 3.5).

Figure 3.5. Policy overlaps along the charcoal value chain



Source: Transrisk 2018

Despite the enactment of the charcoal regulation in 2009, wood harvesting, charcoal production, transport and trade are still unregulated in Kenya. Only 40 per cent of charcoal is produced by groups within registered charcoal producer associations (CPAs) (MEWNR 2013a). This makes regulation of the charcoal business more difficult. A range of international and national policies and regulations guide the charcoal sector in Kenya, as described in Table 3.5.

Table 3.5. Policies guiding the charcoal sector in Kenya

	Policy/regulation/strategy	Policy statement with direct positive influence
1	Energy sector	
	a. Final Draft Energy Policy, 2015	Promotion of LPG through tax exemptions and incentives to reduce use of kerosene, charcoal and firewood. Establishment of a mechanism to eliminate use of charcoal by 2022. Regulation and licensing of charcoal production, transport and trading.
	b. Sessional Paper No. 4 on Energy, 2004	Licencing of charcoal production and promotion of private sector participation in the charcoal sector
	c. Energy Bill, 2015	Promotion of development and use of renewable energy including charcoal. County energy regulations for charcoal producers and dealers
	d. Energy (Improved Biomass Cookstoves) Regulation, 2013	Provides for guidelines on licensing improved cookstove manufacturers, distributers and installers

2	Environment sector	
	a. Environment Management and Coordination Act (EMCA) 1999	EIA is a requirement for all projects involving wood. Promotion of widespread adoption of energy efficient technologies.
	b. National Environment Policy, revised draft 5, 2012	Promotion of alternative, less-polluting technologies to reduce pressure of forests by charcoal production and indoor air pollution from utilization.
	c. National Climate Change Action Plan, 2013	Promotion of more efficient charcoal kilns that have a potential to save 1.6 $MtCO_2e$ annually.
3	Agricultural/Forestry sector	
	Ministry of Agriculture, Livestock and Fisheries	Requirement of a minimum 10 per cent tree cover on farm, and promotion of use of on-farm trees for charcoal production. Promotion of use of improved cookstove
	Ministry of Environment and Forestry	See below
	a. Kenya Forest Services (The forest management and conservation Act, 2016)	Licensing of charcoal production from own farm, private land or community forest or government and county lands. Regulation of production, transport and trade of charcoal
	b. Kenya Forest Services (c. The Forest (Charcoal) Regulation, 2009)	Guidelines on the legal requirement for production, transport and, trade. Formation of formation of charcoal producer groups and associations (CPGs, CPAs).
	d. Sessional Paper No. 9 of 2005 on Forest Policy	Promotion of sustainable production and utilisation of wood. Empowerment of communities to manage forests through community forest associations. Promotion of production and marketing of charcoal.
	e. Draft National Forest Policy, 2015	Promotion of sustainable charcoal production. Concentration of afforestation programmes in community and private land to achieve 10 per cent forest cover.
	f. Kenya Forestry Research Institute (KEFRI)	Research and development of sustainable biomass energy production and use technologies.
4	Others	
	a. The New Constitution	Schedule IV, Chapter 22 promotes protection of the environment and natural resources for durable and sustainable development including energy.
	b. Kenya Second National Communication to the UNFCCC	Introduction of more efficient kilns for charcoal production with an abatement potential of 1.56 $MtCO_2e$ per year by 2030.
	c. Kenya SEforALL strategy:	Target of 100 per cent access to modern cooking solutions by 2030.
	d. Africa's Agenda 2063	Priority area 4, 2023 target: Six of the first goal aims at increasing the efficiency of household energy usage by at least 30 per cent by 2023.
	e. Sustainable Development Goal (SDG) 7	Targets access to affordable, reliable, sustainable and modern energy services for all by 2030.
	f. Kenya Vision 2030	Increased efficiency in energy consumption.

At the local level, some counties, such as Narok, have developed charcoal- and environment-related regulations, while Kajiado, Kwale and Taita Taveta are in the process. On the other hand, several counties including Kitui have banned commercial charcoal production for sale outside the county despite developing a County Charcoal Management bill in 2014.

At the national level, in early 2018 the Ministry of Environment and Forestry imposed the current moratorium on logging and timber harvesting in all public and community forests. This was a result of public outcry about the wanton destruction of forests and water catchment areas and unregulated charcoal production and trade. On 24 February 2018, a 90-day moratorium was imposed, which was later extended to 24 November 2018 and then to the end of 2019.

A national taskforce (MEF 2018) was appointed to provide national recommendations and to review the statutory and regulatory regime governing charcoal production and trade, as well as to make recommendations on the way forward. The taskforce noted that the business remains largely unregulated despite the high economic potential, given the value of the commodity. Some of the taskforce recommendations included identification and promotion of fast-growing tree varieties for charcoal production and the development of standards and certification processes (MEF 2018).

3.2.8 Case-study approach

Charcoal is a commonly used cooking and heating fuel in both urban and rural areas. The sector supports livelihoods and generates revenue for the government, but the current practices need improvement to meet the deficit in a sustainable way. As such there is a need for social-economic and environmental assessment of the sustainability of charcoal for effective planning and development of technologies and business models. This will lead to a socially-culturally acceptable, economically viable and environmentally sustainable charcoal sector.

Nairobi is the county that consumes the most charcoal in Kenya, and 70 per cent of the charcoal consumed in the county is produced mainly in Kitui and Narok counties. This was the focus of the analysis performed with the indicators. For Kitui, a 175 kilometre distance to the market (Nairobi) was used, while for Narok a 141 kilometre distance was used. The results were computed in two likely scenarios.

In the improved scenario, which assumes "good practice", the truck loaded with goods goes to collect charcoal. It is assumed that 80 per cent of charcoal production is from improved kilns, and that the adoption of improved cookstoves rises to 80 per cent. In this practice, charcoal producers are sensitized and dry the wood to around 20 per cent moisture content before carbonizing it to increase yield.

The reference scenario assumes common but unsustainable charcoal production and use. Most often, wood for charcoal is never dried, and the adoption of improved kilns stays at 10 per cent. It is also assumed that a dedicated truck is makes the trip for charcoal delivery.

3.3 References

Agriculture and Food Authority, Sugar Directorate (2017). *Year Book of Statistics 2017*. Nairobi.

Agriculture and Food Authority, Tea Directorate (2019). Personal communication.

Bailis, R. and Hyman, J. (2011). Developing enabling frameworks for dissemination of clean-burning fuel-efficient cookstoves (page: 57-72). In: Haselip, J., Nygaard, I., Hansen, U. and Ackom, E. (2011) (Eds.) *Diffusion of Renewable Energy Technologies: Case Studies of Enabling Frameworks in Developing Countries*. Technology Transfer Perspectives Series, UNEP Risø Centre, Denmark.

Bailis, R., Wang, Y., Drigo, R. and Ghilardi, A. (2017). Getting the numbers right: Revisiting woodfuel sustainability in the developing world. *Environmental Research Letters* 12, 115002.

Clean Cooking Alliance (2019). *Kenya Country Action Plan 2013*. https://www.cleancookingalliance.org/resources/236.html.

Dardamanis, A., Mai-Moulin, T. and Junginger, M. (2015). *Biomass Use and Potential for Export to the European Union from 2015 to 2030. Kenya.* Deliverable 3.1 Biotrade2020+. Intelligent Energy funded project.

FAOSTAT (2019). Forestry production and trade. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/.

Government of Kenya (2005). Forests Act. 2005:229-305. doi:10.1073/pnas.0703993104.

GVEP International (2010). *Kenya Briquette Industry Study*. Deep EA. London.

Iiyama, M., Chenevoy, A., Otieno, E., Kinyanjui, T., Ndegwa, G., Vandenabeele, J., Njenga, M. and Johnson, O. (2014) Achieving sustainable charcoal in Kenya: Harnessing the opportunities for cross-sectoral integration. Technical Brief. Nairobi, Kenya: World Agroforestry Centre/Stockholm Environment Institute.

Kitheka E. M, J. M. Kimiti, N. Oduor, and W. J Mutinda. (2017). Adoption of biomass Energy Conservation Technologies in Selected Areas of Kitui County, Kenya. A paper presented at the 3rd STI&E Conference of Dedan Kimathi University of Technology. Proceedings of the 3rd DeKUT International Conference on STI&E 1st – 3rd November, 2017; Pg 403- 413

Mbaabu, P.R., Ng, W.-T., Schaffner, U., Gichaba, M., Olago, D., Choge, S., Oriaso, S. et al. (2019). Spatial evolution of *Prosopis* invasion and its effects on LULC and livelihoods in Baringo, Kenya. *Remote Sensing* 11, 1217.

Ministry of Energy (2002). *Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small scale Industries and Service Establishments*. Final report. Nairobi. P. 160.

Ministry of Energy and Clean Cooking Alliance (2019). *Kenya Cooking Sector Study: Assessment of the Supply and Demand of Cooking Solutions at the Household Level*. https://www.eedadvisory.com/wp-content/uploads/2019/11/moe-2019-cooking-sector-study-.pdf

Ministry of Environment and Forestry (2018). *Task Force Report on Forest Resources Management and Logging Activities in Kenya*. http://www.environment.go.ke/wp-content/uploads/2018/05/Task-Force-Report.pdf.

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of the Charcoal Value Chain in Kenya*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Ministry of Environment, Water and Natural Resources (2013b). *Analysis of Demand and Supply of Wood Products in Kenya*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%20Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Mugo, F., Nungo, R., Odongo, F., Chavangi, N. and Abaru, M. (2007). *An Assessment of the Energy Saving Potential and Heat Loss Pattern in Fireless Cooking for Selected Commonly Foods in Kenya.* CARPA Working Paper Series No. 2.

Mutimba, S. and Barasa, M. (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainable Charcoal Industry in Kenya.* Energy for Sustainable Development Africa.

Oduor, N (2012). Sustainable feedstock management for charcoal production in Kenya. A production of Practical Action Consulting. Printed by Practical Action Consulting UK. pp 65

Transrisk (2018). Transition pathway and risk analysis for climate change projects. http://www.transrisk-project.eu. Accessed May 2019.

4 RESULTS OF THE GBEP SUSTAINABILITY INDICATORS FOR BAGASSE BRIQUETTES AND CHARCOAL IN KENYA

4.1 Indicator 1. Life cycle greenhouse gas emissions

4.1.1 Definition

(1.1) Life cycle greenhouse gas emissions from bioenergy production and use.

4.1.2 Measurement unit(s)

Grams of CO_2 equivalent per mega joule (gCO_{2eq}/MJ)

4.1.3 Overall methodology of the implementation

In the life cycle greenhouse gas emissions analysis for both bagasse briquettes and charcoal, an Excel-based toolkit developed by the Institut für Energie-und Umweltforschung Heidelberg (IFEU) adopting national data was used. The greenhouse gases covered included carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) and were reported in grams (g) of CO_2-equivalent per megajoule (MJ) of heat produced.

BAGASSE BRIQUETTES

Regarding bagasse briquettes, a complete lifecycle approach was adopted for briquette production, transport and use. A mix of primary data and secondary literature was used. Some key assumptions made in the computation included:

- Most briquette manufacturing plants are based within sugar factories or near sugar factories and use electricity.
- Bagasse is commonly sun dried and manually lifted to the machinery.
- Default emission factors from the Intergovernmental Panel on Climate Change (IPCC) were adopted.

Other data used in the calculations included the following: (i) moisture level of bagasse at point of collection, (ii) transport distance of bagasse collection, (iii) water content upon drying, (iv) electricity consumption per ton of produced briquettes, (v) transport distance travelled to ferry briquettes to point of use, and (vi) end use boiler efficiency.

Bagasse residues are high in moisture content (50 per cent) and need to be dried to 18-20 per cent for briquetting (FAO 1996, 2014; SERC 2017). Auxiliary energy (electricity) use in briquetting is from the national grid, with final energy intensity of 50 kilowatt-hours (kWh) per ton of briquette (FAO 1996). The final product (briquette) is transported around 660 kilometres round-trip as estimated by the two case study industries – tea industry “Y” sources its briquettes from briquette manufacturer “X” with an approximate distance of 330 kilometres in dedicated trucks. The gross efficiency of thermal conversion of briquettes and wood into heat was around 82 per cent. This was an average value based on Strathmore Energy Research Centre (2017) on the 90th percentile of boiler efficiency in the study factories (SERC 2017).

CHARCOAL

For charcoal, a two-step analysis of greenhouse gas emissions was adopted, as summarized in Figure 4.1.

Figure 4.1. Schematic of the steps included in the analysis

Data used in calculation included the following stages: 1) carbonization, which considered the type of kilns used, the mix of traditional and improved kilns, and the efficiency of the kilns, 2) transport, which included the distance and the type of truck transporting the charcoal, and 3) end use, which included a mix of improved and traditional stoves and the conversion efficiency of the stoves. Table 4.1 summarizes the data used for calculations and sources. Production of wood for charcoal was excluded and was assumed to be from native trees managed on farms.

Table 4.1. Summary of the data used in the calculations

	Data description	Reference	Improved scenario	Unit	Source
1	Charcoal kiln: share of improved kiln	10%	80%	per cent	(MEWNR 2013a)
2	Cookstoves: share of improved cookstoves	38%	80%	per cent	(MEWNR 2013a)
3	Water content of fresh wood	50%	50%	per cent	(FAO 2014)
4	Water content after sun drying	50%	20%	per cent	(FAO 2014)
5	Non-improved kilns	0.15	0.15	fraction	(MEWNR 2013b)
6	Improved kilns	0.30	0.30	fraction	(MEWNR 2013b)
7	Charcoal transport distance (Kitui)	282*	141	km	Google Maps
8	Charcoal transport distance (Narok)	350*	141	km	Google Maps
9	Thermal efficiency of traditional charcoal cooking stove	15%	15%	per cent	(World Bank 2012)
10	Thermal efficiency of improved charcoal cooking stove	33%	33%	per cent	(World Bank 2012)

*The distance specified in reference implies a dedicated truck travelling without any other good or product.

For Kitui, a 175 kilometre distance to the market (Nairobi) was used, while for Narok a 141 kilometre distance was used. The results were computed in two likely scenarios.

In the improved scenario, which assumes "good practice", the truck loaded with goods goes to collect charcoal. It is assumed that 80 per cent of charcoal production is from improved kilns, and that the adoption of improved cookstoves rises to 80 per cent. In this practice, charcoal producers are sensitized and dry the wood to around 20 per cent moisture content before carbonizing it to increase yield.

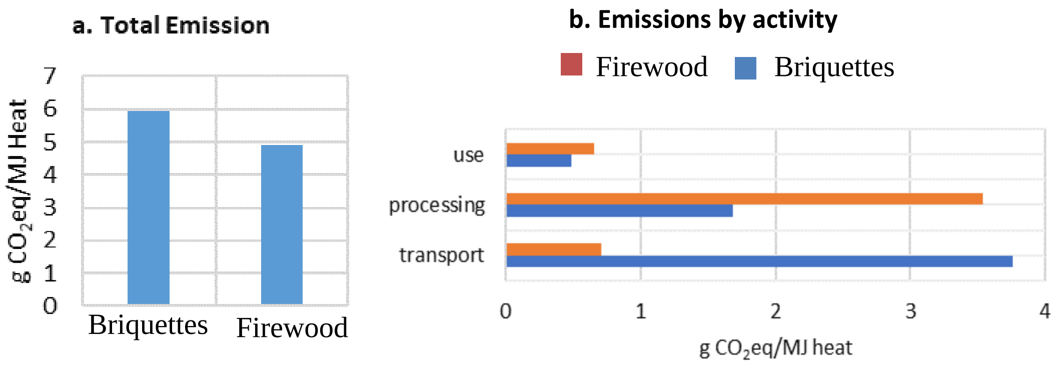
The reference scenario assumes common but unsustainable charcoal production and use. Most often, wood for charcoal is never dried, and the adoption of improved kilns stays at 10 per cent. It is also assumed that a dedicated truck is makes the trip for charcoal delivery.

4.1.4 Key findings

BAGASSE BRIQUETTES

From the life cycle analysis, greenhouse gas emission intensity in using bagasse briquettes was found to be 5.9 gCO_2eq/MJ above the reference, based on the use of wood, which is 4.9 gCO_2eq/MJ. Emissions were around 21 per cent higher in the bioenergy pathway. This is attributed mainly to transport-related emissions, as illustrated in Figure 4.2.

Figure 4.2. a. Total calculated emissions b. Calculated emissions divided by activities

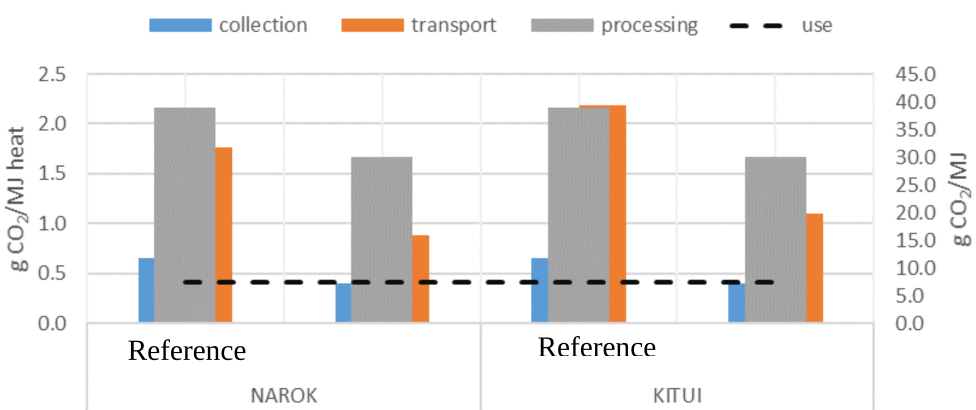


Emissions of methane and nitrous oxide were higher from the combustion of wood than from the combustion of bagasse briquettes. Wood logging and cutting of small pieces results in the higher emissions in processing of wood in the reference case. In contrast, the process emissions for bioenergy emanate from grid emissions based on the emission factor per kWh used during compaction. Large emission from briquettes use, processing and transport thus result from transport of briquettes to tea factories.

CHARCOAL

In the improved scenario, the greenhouse gas emission intensity for Kitui and Narok was around 38 g CO_2eq/MJ, whereas in the reference scenario the greenhouse gas emission intensity for Kitui was 49 g CO_2eq/MJ and for Narok was 48.5 g CO_2eq/MJ. In the two instances, it is observed that emission intensity related to transport is halved 0.9 g CO_2eq/MJ in the improved scenario for Narok and 1.8 g CO_2eq/MJ in the reference scenario for Narok. However, methane emission biogenic resulting from the process constitutes greater greenhouse gas emission (Figure 4.3).

Figure 4.3. Greenhouse gas emissions for the two studied cases and scenarios



From the emissions calculation, in both cases the savings account for around 10 gCO_2eq/MJ heat, which translates to 21 per cent emission saving. The main emissions in the process include transport, collection and process emissions. Process emissions constitute the highest emission intensity with 39 gCO_2eq/MJ heat in the reference scenario and 30 gCO_2eq/MJ heat in the improved scenario. This results from the carbonization process of firewood to charcoal.

4.1.5 Conclusions and recommendations

Synthesis of findings

Regarding bagasse briquettes, the life cycle analysis makes it clear that sustainability of the bioenergy pathway is dependent on two main factors: 1) the scope of the life cycle analysis and 2) the production process and transport of briquettes. From the studied case, there is around 21 per cent more emission in the briquettes case in comparison to the use of firewood. In this case, the analysis scope for the pathway considered the production, transport and use of the briquettes. Otherwise, downstream bagasse handling could be a major contributor to methane emissions if left in unmanaged landfills, and upstream firewood conservation would result in CO_2 sequestration, making briquette use as alternative energy grossly sustainable and with multiple benefits. However, in the described case, transport distance is the major cause of fossil-based CO_2/MJ and methane/MJ heat generated.

Concerning charcoal, processing of wood to charcoal constitutes 81 per cent of the total emission in charcoal production, use constitutes 15 per cent, and transport and collection constitute 2 per cent each. This is due to biogenic methane generation during charcoal carbonization. Biogenic methane has 28 times the global warming potential, resulting in the high observed emission caused by the conversion process. Similarly, cooking emissions result from methane biogenic from the conversion of charcoal to heat. Notably, both traditional and improved charcoal kilns result in biogenic emissions, at levels of 1288.6 gCO_2eq per kilogram of carbonized wood and 879.8 gCO_2eq per kilogram of carbonized wood. Therefore, increasing adoption of improved charcoal production kilns will reduce overall greenhouse gas emissions by around 31 per cent in the improved scenario.

Practices and policies to improve sustainability

Briquettes are transported 333 kilometres from the western region of Kenya (the Kenya sugarcane belt) to central Kenya. Tea is grown in the Kenya highlands of Rift Valley, Mount Kenya, the Aberdares, Nyambene hills, Mau escarpment, Kericho, Nandi and Kisii island, and Cherangani hills (UNIDO 2017). This provides wide distribution of tea industries in western and central Kenya without necessarily needing to transport briquettes for long distances. In a case where western tea zones adopt briquettes, greenhouse gas emission abatement of 0.3 gCO_2eq/MJ results in net emission reduction within the described life cycle analysis scope.

For charcoal, besides the greenhouse gas emissions reduction observed in shifting to more efficient kilns, a change from 10 per cent charcoal conversion efficiency to 30 per cent efficiency would yield 20 per cent wood saving and triple the charcoal yield. Further reduction is achieved when efficient cookstove technologies are used. In this light, technology efficiency promotion is critical considering the national forest cover conservation, reduced indoor air pollution and biodiversity conservation. The energy (improved cookstoves) regulation provides guidelines to installers and manufacturers and licenses all actors in the dissemination of improved cookstoves. Whereas the regulation is much clearer regarding cookstove manufacture and use among institutions, it is fuzzy on the principles of ensuring the adoption and use of improved cookstoves in households.

Future monitoring

For bagasse briquettes, more accurate data on the emissions from boilers fuelled with briquettes and other fuels as well as primary data on emissions from tractors, trucks and lorries used to transport the bagasse feedstock and briquettes could be used to recalculate the results for further monitoring. Life cycle analysis for briquettes made of other agricultural residues, such as coffee husk or pineapple, would be useful information for the Kenyan bioenergy sector.

Regarding charcoal, emission measurements on other kiln types, vehicles and cookstoves would generate data that could be used in future life cycle analysis. Any change in policy regarding charcoal production, trade and consumption would imply a change in the value chain. Life cycle analysis can be used to monitor the effect of a change in policy.

4.1.6 References

Food and Agriculture Organization of the United Nations (1996). *Biomass Briquetting: Technology and Practices.* Rome.

Food and Agriculture Organization of the United Nations (2014). *Bioenergy and Food Security Rapid Appraisal (BEFS RA): User Manual Charcoal*.

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of the Charcoal Value Chain in Kenya.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Ministry of Environment, Water and Natural Resources (2013b). *Analysis of Demand and Supply of Wood Products in Kenya Study.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%2Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Strathmore Energy Research Centre (2017). *Bioenergy Analysis for 30 Factories of the Kenya Tea Development Agency Holdings Company Ltd (KTDA).*

United Nations Industrial Development Organization (2017). *Adaptation and Mitigation in the Kenyan Tea Industry.* https://www.unido.org/sites/default/files/2017-03/Kenya-country-report-DIGITAL-FINAL-20170302-OnePage_0.pdf.

World Bank (2012). *Establishing a Green Charcoal Value Chain in Rwanda.* Feasibility study report.

4.2 Indicator 2. Soil quality

4.2.1 Definition

(2.1) Percentage of land for which soil quality, particularly in terms of soil organic carbon, is maintained or improved out of total land on which bioenergy feedstock is cultivated or harvested.

4.2.2 Measurement unit(s)

Percentage (%)

4.2.3 Overall methodology of the implementation

Charcoal industry has led to increased destruction of trees and vegetation due to increased charcoal demand and the use of inappropriate technologies in charcoal production. Use of traditional charcoal kilns accelerates the destruction due to low efficiency (Müller et al. 2011). The harvesting of

tree resources for charcoal has generally led to forest degradation. However, there is limited information on the effects on soil quality of tree harvesting for charcoal and fuelwood.

A review of soil types and land degradation is proposed.

The methodological approach was adapted to the set of conditions found in Kenya. It was not possible to carry out direct soil surveys and consequent analyses of soil organic carbon and other parameters related to soil quality. Therefore, secondary data were retrieved from the relevant institutions in the country and analyses were performed. Information and data were obtain from national and international technical reports as secondary data.

4.2.4 Key findings

Soil types and distribution

Kenya has a very wide range of soils resulting from the variation in geology (parent material), in relief and climate. Soil resources vary from sandy to clayey, shallow to very deep and low to high fertility. However, most of them have serious limitations such as salinity/sodicity, acidity, fertility and drainage problems. Using the FAO classification system, the country has 25 major soil types (Map 4.1). However, in terms of geographic coverage, 15 soil types dominate: Acrisols, Alisols, Andosols, Arenosols, Calcisols, Cambisols, Ferralsols, Fluvisols, Lixisols, Luvisols, Nitisols, Regosols, Solonetz, Planosols and Vertisols. Around 59 per cent of Kenya's soils have moderate to high fertility, meaning they are theoretically suitable for growing crops. Among these, the major soils used in agriculture in Kenya include:

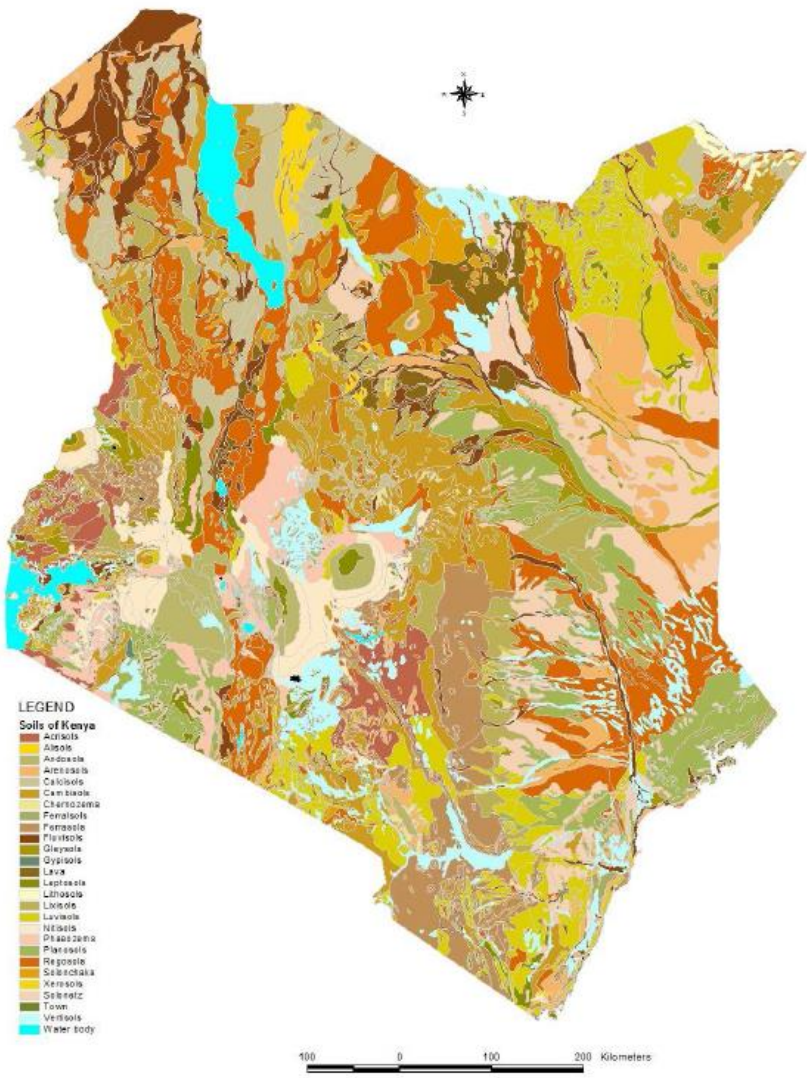
- *Nitisols* occur in the highlands and on volcanic steep slopes, for example in the central highlands of Kenya around Mount Kenya and Mount Kilimanjaro. Nitisols often have a high clay content (more than 35 per cent) and are the best agricultural soils found in Kenya. They intensely used intensely for plantation crops and food production (e.g., bananas, tea and coffee). They are developed from volcanic rocks and have better chemical and physical properties than other tropical soils. They have a good moisture-storage capacity and aeration, and the organic matter content, the cation exchange capacity and the percentage base saturation range from low to high. Most Nitisols are acidic (pH < 5.5) due to the leaching of soluble bases. For optimal agricultural production, nitisols require the use of manure and inorganic fertilizers.

- *Andosols* (young volcanic soils) occur in areas with steep slopes and high rainfall. Through rainfall of over 1,000 millimetres per year, andosols are exposed to excessive leaching. Andosols are porous and have a high water-storage capacity and a low bulk density. They are also acidic (low pH) due to the high leaching of soluble bases and to high levels of aluminium. These conditions favour phosphorous fixation, making the phosphorous no longer available to the plants. To improve agricultural production, liming and the use of fertilizers is necessary. Andosols are highly susceptible to erosion as they mostly occur on steep slopes. In these areas, they are mainly used for tea, pyrethrum, temperate crops and dairy farming.

- *Acrisols, Alisols, Lixisols and Luvisols* occur in the coffee zones in sub-humid areas, on undulating to hilly topography. They show an increase of clay content in the sub-soil (B-Horizon). The sub-soil is often not very porous, impeding root spreading. They have a relatively low water-storage capacity, compared with nitisols. Acrisols and Alisols in wet areas have a low pH (acid), aluminium and manganese toxicities, and low levels of nutrients and nutrient reserves. These soils have poor structure and require erosion control measures. Organic and inorganic fertilizers are needed to improve crop production. The soils respond well to fertilizers (especially nitrogen, phosphorous and potassium) and to the use of soil organic matter.

- *Planosols and Vertisols* occur on very gently undulating to flat topography, mostly in rice-growing areas, for example, Mwea in Kirinyanga County and Kano plains in Kisumu. They are found in semi-arid and sub-humid environments. Due to the high clay content in the subsoil (higher than in the top soil), this layer in the B-horizon is impermeable, resulting in very slow vertical and horizontal poor drainage and also in extremely poor workability of the soils. Vertisols are dark coloured, strongly cracking clays, which are best used for irrigated paddy rice and other crops that can withstand temporary waterlogging.
- *Ferralsols* occur on gently undulating to undulating topography. They are very old, highly weathered and leached soils, and therefore have poor fertility, which is restricted to the top soil, as the subsoil has a low cation exchange capacity. Phosphorous and nitrogen are always deficient. Ferralsols are rich in aluminium and iron. The nutrient reserves are easily disturbed by agricultural practices. Important management practices include the use of fertilizers (e.g., rock phosphate) and the maintenance of soil organic matter by using green manures, farmyard manures and mulching. Ferralsols also have good physical properties, including an excellent capacity to hold moisture, and are used to grow annual crops.

Map 4.1. Major soil types in Kenya

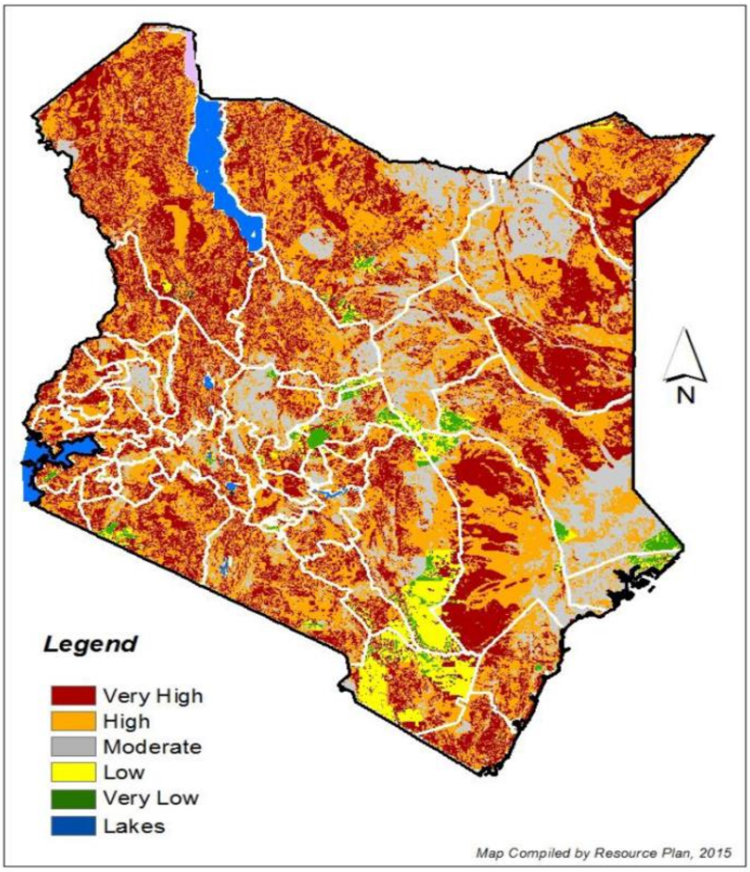


Source: Resource Plan 2016

Land degradation in Kenya

Land degradation is an indication of temporary or permanent long-term decline in ecosystem function and productive capacity. Land degradation was determined through remote sensing and geographic information system (GIS) mapping by combining various factors including: land use / land cover, rainfall amounts, soil erodibility and topography; after delineating protected areas, the results shown in Map 4.2 were obtained. Spatial analysis (Table 4.2) showed that only around 2.2 per cent of the country's land area has minimal risk of degradation through soil erosion. The rest suffers moderate to very severe degradation, with the largest proportion (61.4 per cent) being at risk of severe land degradation. High erosion risk even extends to protected areas such as national parks due to the encroachment of human activities and the natural propensity for erosion, e.g., high soil erodibility, drought and flood risks, as well as declining vegetation cover.

Map 4.2. Land degradation in Kenya based on remote sensing / GIS mapping reference



Source: Compiled by Resource Plan 2016

Soil erosion is thus a major factor in land degradation and has severe effects on soil functions, such as the soil's ability to act as a buffer and filter for pollutants, its role in the hydrological and nitrogen cycle and its ability to provide habitat and support to biodiversity. Although soil erosion is a natural geomorphic process, human activities such as poor cultivation, overgrazing and deforestation (excessive removal of trees for timber and wood fuel) accelerate the process beyond the acceptable levels. Excessive erosion is associated with diverse negative on- and off-site impacts, including loss of soil nutrients, leading to a reduction in crop yields and decreasing stream competence and capacity because of sedimentation and siltation of reservoirs.

Table 4.2. Status of land degradation in Kenya

Degradation class	Area (km^2)	Per cent (%)
Very low	4 548	0.8
Low	8 225	1.4
Moderate	52 383	9.2
High	350 992	61.4
Very high	155 268	27.2
Total area (km^2)	571 416	100.0

Source: KASLMP 2016

Effect of land use on soil organic stocks

Soil organic carbon, including its quantity and quality, is the defining constituent of soil (Krupenikov et al. 2011; Manlay et al. 2007). Indeed, soil organic carbon is the most reliable indicator of monitoring soil degradation, especially that caused by accelerated erosion (Rajan et al. 2010). Soil degradation depletes the soil organic carbon, and along with it the plant-available nitrogen and other essential nutrients such as phosphorous and sulphur. Research has shown that depletion of soil organic carbon is a global issue and is a principal cause of soil degradation, especially in semi-arid regions (Diacono and Montemurro 2010).

Developing strategies to increase soil organic carbon and preferably maintain it above the threshold or critical level of 10 to 15 grams per kilogram (1.0 per cent to 1.5 per cent) is essential for reducing soil degradation risks and reversing degradation trends. Integrated nutrient management (INM) is one strategy that embodies sustainable management of soil organic carbon and its dynamics (Vanlauwe et al. 2012). Adoption of INM or similar management practices that create a positive soil/ecosystem carbon budget can not only increase productivity but also sequester additional atmospheric CO_2 into the soil organic carbon pool. There also exists a strong relationship between vegetation cover and soil organic carbon, such that excessive reductions in vegetation cover exacerbates risks of soil degradation and soil organic carbon depletion.

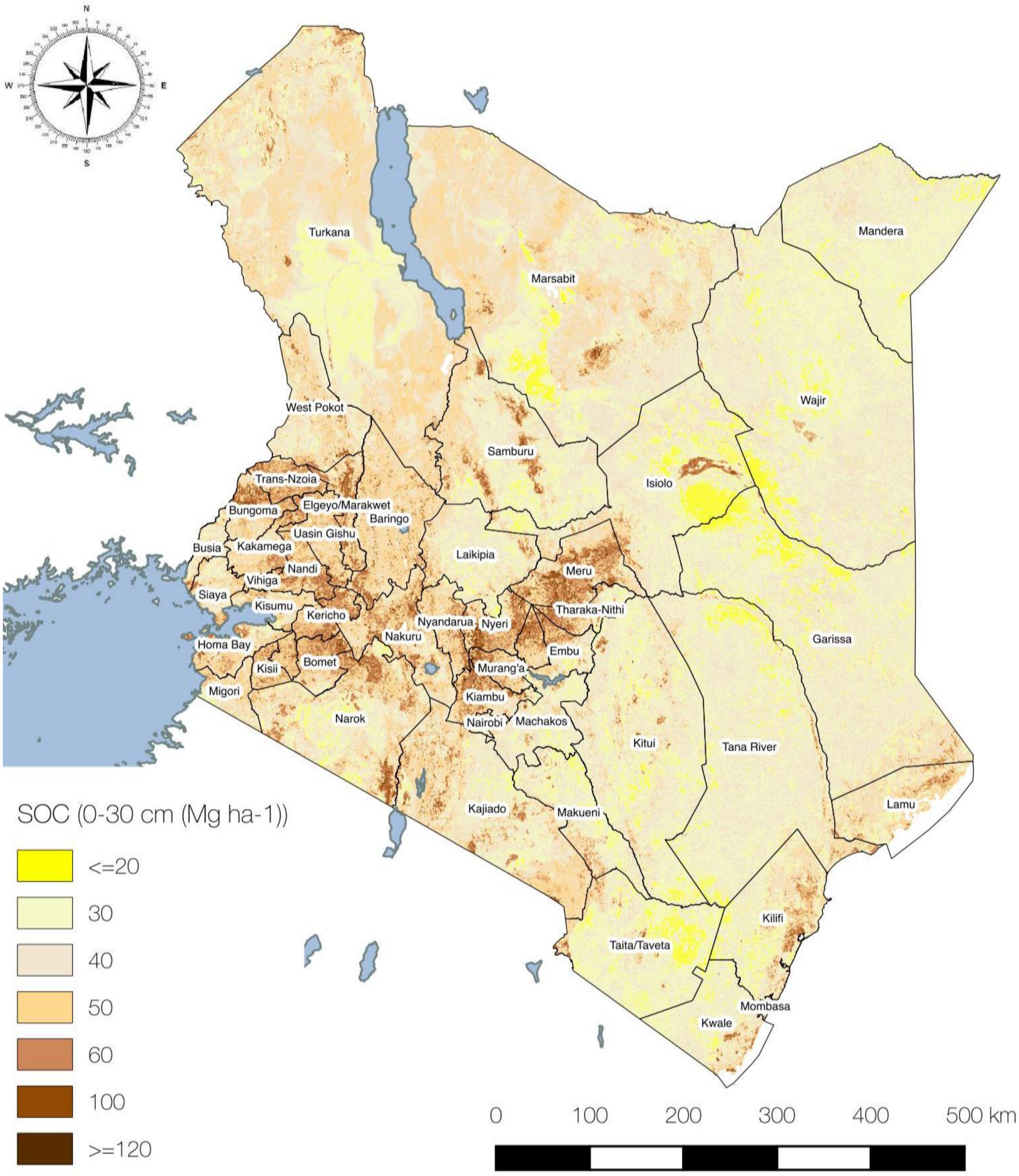
A study conducted in the sub-tropical humid grasslands in South Africa indicated that the decline in grass (vegetative) cover from 100 per cent to only 0 per cent to 5 per cent reduced the soil organic carbon by 1.25 kilograms per m^2 and the soil organic nitrogen by 0.074 kilograms per m^2 (Dlamini et al. 2014). There were also attendant declines in the carbon-to-nitrogen ratio and the proportion of soil organic carbon and soil organic nitrogen in the silt and clay fraction with the decline in aerial grass cover, which negatively affected ecosystem functions of the acidic sandy loam soils.

Similarly, transformation of a thicket vegetation to an open savannah (dominated by grasses) due to intensive grazing decreased soil quality in the Eastern Cape region of South Africa (Mills and Fey 2004). Savannah soils have lower soil organic carbon concentration and a greater tendency to crust than thicket soils because of the decreased quantity and stability of structural aggregates. The soil organic carbon pool of agricultural soils of West Africa, similar to those of croplands in other developing counties (e.g., South Asia), is severely depleted by over-exploitation of natural resources (Lal 2004). These soils must therefore be managed to increase both soil carbon and vegetation (Lal 2005; Batjes 2001) to restore the degraded agro-ecosystem services. Changes in aerial vegetative cover could thus be used as an early indicator of shifts in soil ecosystem functions within fragile environments.

Soil organic stocks in Kenya

Spatial estimates of soil organic carbon stocks for Kenya show that Kenyan soils store around 2.4 gigatons (Gt) of carbon in the upper 30 centimetres of the soil profile (Minasny et al. 2017). Average soil organic carbon stocks for Kenya were estimated to be 42 milligrams of carbon per hectare (Map 4.3) for 0 to 30 centimetre depth. The lowest estimated carbon stocks were found in arid and semi-arid regions of the country (<20 milligrams of carbon per hectare on average), such as Turkana County.

Map 4.3. Soil organic carbon stock map of Kenya at 500-metre resolution, 2012



Source: Vågen et al. 2018

These estimates are consistent with those reported by Batjes and Batjes (2004) for arid and semi-arid parts of the country. Higher soil organic carbon stocks were found in sub-humid and humid areas, including the central highlands and western parts of the country (Map 4.3). The highest soil organic carbon stocks are found in forest systems, such as around Mount Kenya (>100 milligrams of carbon per hectare), the Aberdares, the Mau Forest Complex and Kakamega Forest. These forest

systems, while making up a small proportion of the country's area, are critical carbon pools and also represent important water towers that millions of Kenyans rely on for their water supply (Mogaka et al. 2005). Also, wetland ecosystems such as inland riverine and palustrine areas are critical soil organic carbon pools in Kenya and in much of Eastern Africa. In the drylands, such wetland systems are particularly critical for soil organic carbon storage and land health, frequently reaching between 80 and 100 milligrams of carbon per hectare at 0 to 30 centimetre depth. Other wetland systems, many of them under threat, such as around the Rift Valley lakes and lacustrine wetlands along Kenya's coast, are also examples of ecosystems that are critical for carbon storage (Minasny et al. 2017; Saunders et al. 2007) and other ecosystem services (Zedler and Kercher 2005) in the country.

4.2.5 Conclusions and recommendations

Synthesis of the findings

Wood will continue to be a key source of energy for cooking, boiling water, lighting and heating in many households in Kenya. Much of this wood will continue to be sourced from agroforestry, trust lands and gazetted forests. However due to increased wood demand this will lead to increased degradation of vegetation cover and consequently soil quality. There is need for options to restore degraded lands as a result of vegetation depletion resulting from cutting for fuelwood.

The overriding conclusion of the work on this indicator is that there is insufficient baseline data and monitoring of soil organic carbon and other key soil quality parameters, including soil management practices. While increased (and methodical) soil quality monitoring in key sugar cane and eucalyptus areas would be advantageous, the organization of information on the implementation of good agricultural practices (GAPs) that should favour soil quality (including soil organic carbon) maintenance or increases would seem a cost-efficient alternative or complement.

Practices and policies to improve sustainability

Site-specific techniques for restoring soil quality include conservation agriculture, integrated nutrient management, and continuous vegetative cover such as residue mulch and cover cropping, and controlled grazing at appropriate stocking rates.

Future monitoring

The difficulties encountered during the measurement of this indicator highlighted the need for harmonized time series of soil quality data for parameters of interest. Moreover, primary data collection activities, soil sampling in the field and *in situ* and laboratory analyses of the samples should be performed at appropriate intervals as proposed by the GBEP methodological approach. In the literature, information of this kind is scarce for Kenya, and the assumptions required may affect the establishment of baseline values and the monitoring of soil quality.

It is therefore suggested to perform a primary data collection campaign in the areas used for bioenergy feedstock production aiming to analyse soil organic carbon content and other parameters of interest for this indicator (e.g., conductivity, salinity, erosion and compaction, among others). Furthermore, it is recommended to involve land owners/managers and bioenergy producers for the collection of primary data in the field. This is particularly the case for soil organic carbon content in the soils used for bioenergy feedstock production, where the scarce literature that was found has presented inconsistent results.

The measurement of biophysical parameters should be complemented by a systematic surveying of soil management practices to determine whether risks to soil quality are being managed adequately and to gain a better understanding of how soil quality could be improved in areas of bioenergy feedstock production. This would require the compilation of good practices suited to specific soil and agro-ecological conditions and crops, building on what is already known within the sector.

4.2.6 References

Batjes, N. (2001). Options for increasing carbon sequestration in West African soils: An exploratory study with special focus on Senegal. *Land Degradation & Development* 12, 131-142.

Batjes, N. and Batjes, N. (2004). Soil carbon stocks and projected changes according to land use and management: a case study for Kenya. *Soil Use Management* 20, 350-356.

Diacono, M. and Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility: A review. *Agronomy for Sustainable Development* 30, 401-422.

Dlamini, P., Chivenge, P., Manson, A. and Chaplot, V. (2014). Land degradation impact on soil organic carbon and nitrogen stocks of sub-tropical humid grasslands in South Africa. *Geoderma* 235, 372-381.

Krupenikov, I., Boincean, B. Dent, D.(2011). Humus: Guardian of fertility and global carbon sink. In: *The Black Earth: Ecological Principles for Sustainable Agriculture on Chernozem Soils. International Year of Planet Earth 2011*. Springer: Dordrecht, The Netherlands, 2011; pp. 39-50.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science* 304, 1623-1627.

Lal, R. (2005). Soil carbon sequestration in natural and managed tropical forest ecosystems. *Journal of Sustainable Forestry* 21, 1-30.

Kenya Agricultural Productivity and Sustainable Land Management Project (KASLMP) (2016). *Land Degradation Assessment In Kenya Report 2016*.

Manlay, R., Feller, C. and Swift, M. (2007). Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. *Agriculture, Ecosystems & Environment* 119, 217-233.

Mills, A. and Fey, M. (2004). Transformation of thicket to savanna reduces soil quality in the Eastern Cape, South Africa. *Plant Soil* 265, 153-163.

Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., Chaplot, V. et al. (2017). Soil carbon 4 per mille, *Geoderma* 292, 59-86.

Mogaka, H., Gichere, S., Davis, R. and Hirji, R. (2005). *Climate Variability and Water Resources Degradation in Kenya*, World Bank, Washington, D.C.

Müller, N., Michaelowa, A. and Eschman, M. (2011). *Proposal for a New Standardized Baseline for Charcoal Projects in the Clean Development Mechanism*. Zurich. p. 86.

Rajan, K., Natarajan, A., Kumar, K., Badrinath, M. and Gowda, R. (2010). Soil organic carbon—the most reliable indicator for monitoring land degradation by soil erosion. *Current Science* 99, 823-827.

Resource Plan (2016). Land Degradation Assessment (LADA) in Kenya. Based on a Study of Land Degradation Assessment (LADA) with Remote Sensing and GIS, for Sustainable Land Management (SLM) in Kenya. http://www.environment.go.ke/wp-content/uploads/2018/08/LADA-Land-Degradation-Assessment-in-Kenya-March-2016.pdf

Saunders, M. J., Jones, M. B. and Kansiime, F. (2007). Carbon and water cycles in tropical papyrus wetlands. *Wetlands Ecology and Management* 15, 489-498.

Vågen, T., Winowiecki, L.A., Neely, C., Chesterman, S. and Bourne, M. (2018). Spatial assessments of soil organic carbon for stakeholder decision-making - A case study from Kenya. *SOIL* 4, 259–266.

Vanlauwe, B., Hester, R. and Harrison, R. (2012). Organic matter availability and management in the context of integrated soil fertility management in sub-Saharan Africa. *Soil and Food Security* 35, 135-157.
Zedler, J. B. and Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources* 30, 39-74.

4.3 Indicator 3. Harvest levels of wood resources

4.3.1 Definition

(3.1) Annual harvest of wood resources by volume and as a percentage of net growth or sustained yield, and the percentage of the annual harvest used for bioenergy.

4.3.2 Measurement unit(s)

Cubic metres per hectare per year (m^3/ha/year), tons/ha/year, m^3/year or tons/year, percentage

4.3.3 Overall methodology

A literature review was done to gather data on the annual harvesting of forests in Kenya and on the current situation regarding the banning of charcoal production, which has an impact on harvesting. Although analysed at a national level, the wood harvest was estimated for charcoal production and for fuelwood used in tea plantations.

The main challenge is the mechanism for estimating how much bioenergy can be produced from wood residues (branches, treetops, bark). The analysis was based on data for the period 2010-2015 on forests and woodlands, their productive capacity and wood removals available for bioenergy, provided in different reports (MENR 2016; FAO 2015; Muchiri and Muga 2019). Volumes were computed for different tree ages and sizes from sample plots data acquired in forest inventory surveys in natural and plantation forests.

4.3.4 Key findings

Kenya's forests cover an area of 4,986,676 hectares, of which natural forests cover 4,754,378 hectares while plantations cover 232,298 hectares. Public or gazetted natural forests cover 905,357 hectares. Natural forests in community lands cover 3,849,021 hectares, of which 596,099 hectares were national parks; hence 3,252,922 hectares is the forested area under community management. Public plantations cover 138,152 hectares, and community/private plantations cover 94,146 hectares.

The forests in Kenya are divided into public and community/private forests. The country's farm forestry programme also has a high proportion of trees on farmlands, which are also considered part of the supply of wood in Kenya (and within this study, supply from these tree resources is considered in the supply analysis). Public forests, managed by the government for the provision of forest goods and services, cover an area of 1,043,509 hectares; plantations cover 138,152 hectares, and natural forests occupy an area of 905,357 hectares (MEWNR 2013).

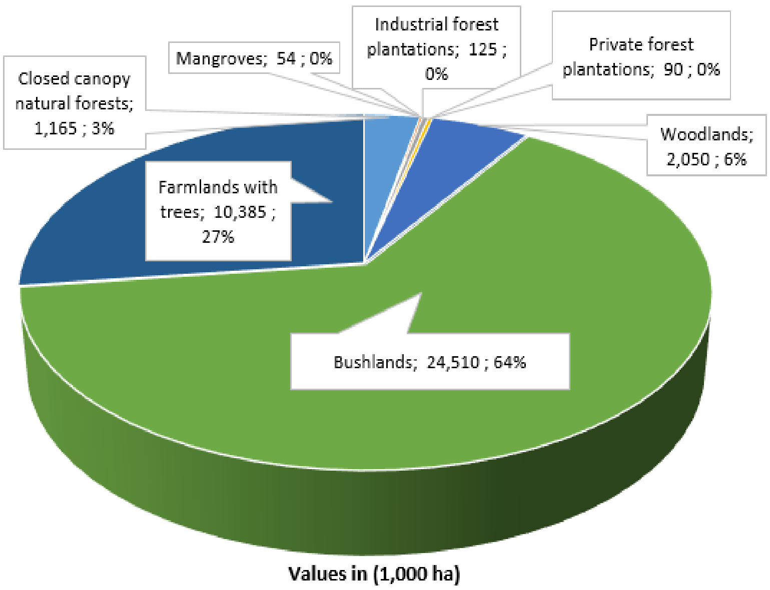
The Constitution of Kenya requires a minimum tree cover of 10 per cent of the total land area. To address this problem, the Government has declared a moratorium on harvesting of timber and commercial charcoal production on all public and community forests for 90 days, which took effect in 24 February 2018 and was extended to 2019. The purpose of the moratorium was to allow for reassessment and rationalization of the entire forest sector (MEF 2018). The total forest land in Kenya was projected to be 7.5 per cent (MENR 2016) of the country's total area of 582,646 km^2. These forests have suffered deforestation and degradation that have adversely affected many ecological processes, impacting services such as the soil-water relationship (Map 4.4).

Forest cover loss in Kenya, a largely agricultural country, can be attributed mostly to agricultural expansion (MFW 2013). Forests provide goods and services including bioenergy, wildlife habitat, biological diversity, water catchment, employment opportunities and livelihood sources. The forests are also threatened by over-exploitation, unsustainable use of forest resources; population increase, and widespread unemployment of a large portion of the population. Kakamega Forest, for example, has suffered from continued overuse for timber, charcoal, firewood, cash crops and conversion to forest plantation.

Forests in Kenya are classified into four categories and include natural forests, dryland forests, plantations, and coastal forests and mangroves (SLEEK 2018). Natural forests are made up of the western rain forests and montane forests (4.04 million ha), bamboo forest (59,000 hectares); public plantations (122,000 hectares); private plantations (71,000 hectares); woodlands, mainly in the dry lands of the country (9.65 million hectares); and mangrove (49,000 hectares) (FAO 2015). In recent years, forest land has increased from 6 per cent to 7 per cent, although the data vary by organisation (Figure 4.4).

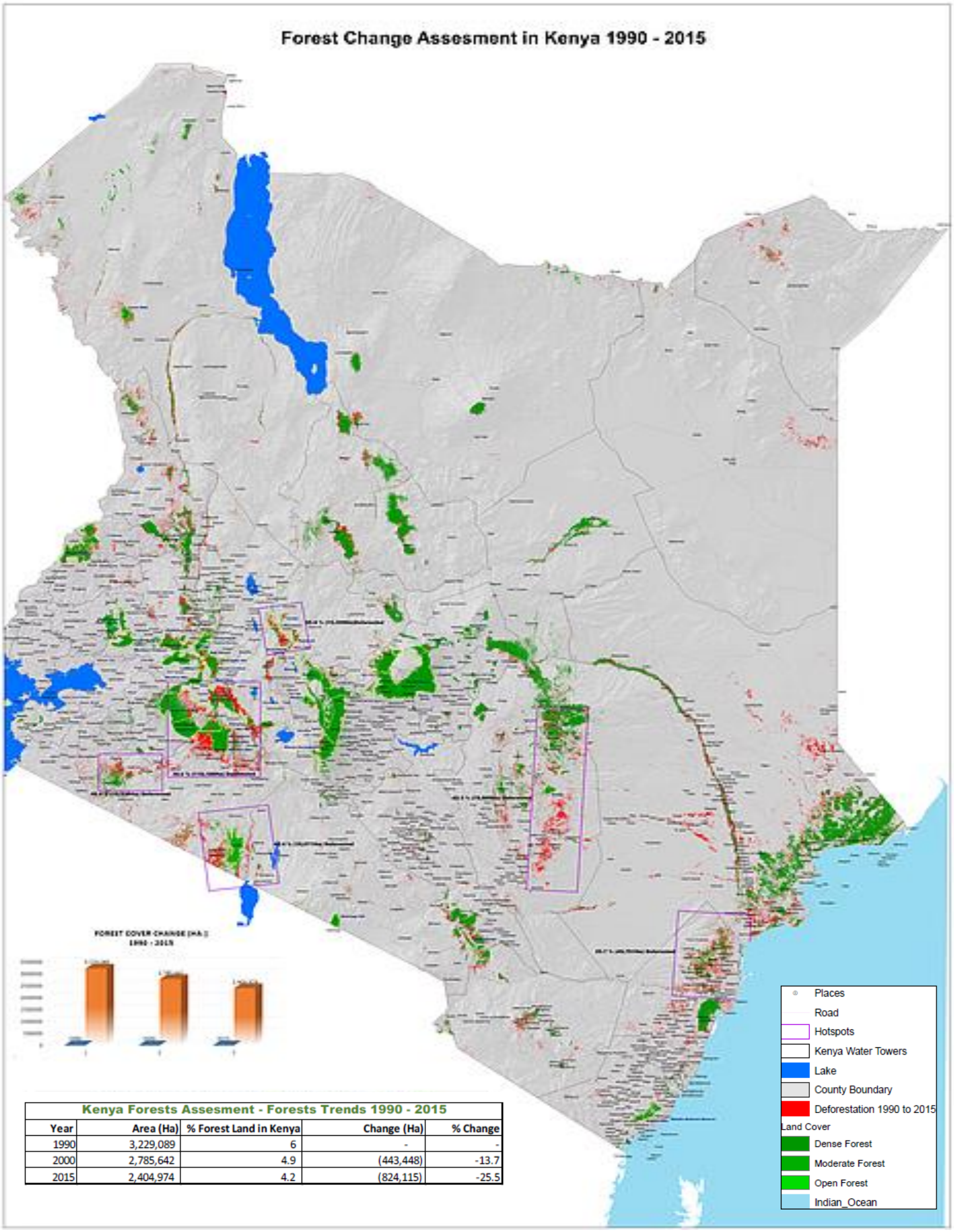
Through the System for Land-based Emissions Estimation in Kenya (SLEEK) project, Kenya has adopted a four-zone forest classification (Map 4.5), which includes the Montane/Western Rain forest/Bamboo; Dryland Forest; Coastal Forest/Mangrove and Plantation Forest.

Figure 4.4. Forest states in Kenya



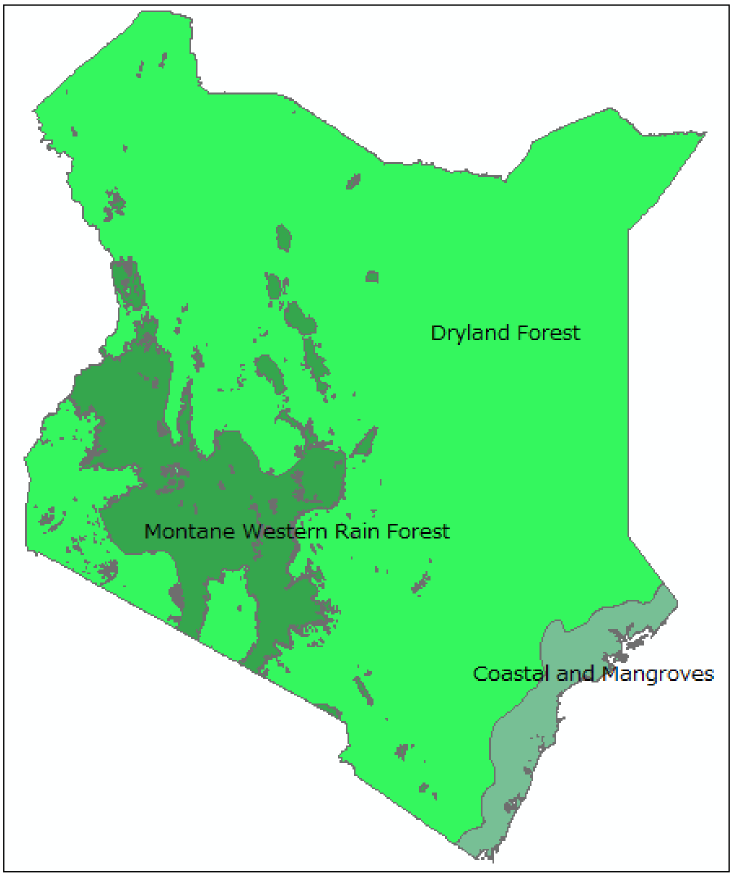
Source: OFESA 2019

Map 4.4. Key deforestation hotspots in Kenya



Source: WWF 2019

Map 4.5. Forest strata zones in Kenya



Source: SLEEK 2018

Most (77 per cent) of the forest land in Kenya is under community and private ownership while the rest (23 per cent) is public. Private plantations cover 37 per cent of the total forest plantation area, which is almost equal to the area of stocked plantations under public management. The total wood supply in 2012 was 31,405,060 m^3 against a demand of 41,700,664 m^3 (MEWNR 2013).

Table 4.3. Total wood supply by product in Kenya 2012

Timber (m^3)	Poles (m^3)	Firewood (m^3)	Charcoal (m^3)
7 363 41	3 028 907	13 654 022	7 358 717

Source: MEWNR 2013

An estimated summary of yields (m^3/ha) for different forest types was produced by the Ministry of Environment, Water and Natural Resources (2013), as indicated in Table 4.4.

Table 4.4. Yields for different forest types and products in Kenya

		Wood products			
Forest types	**Rotation period**	**Timber**	**Poles**	**Fuel wood**	**Total**
	years	**m^3/ha**			
Natural forests (public and community)	-	0.4	0.2	0.9	1.5
Public plantation forests	28	262.2	44.5	100.8	407.5
Community/Private plantations	21	88.2	140.7	178.5	407.4
Trees on farms	8	3.5	1.2	12.8	17.6

Source: MEWNR 2013

The leftovers after harvesting of plantations (small stems, tops, branches and the bark) constitute the bulk of the fuelwood used by tea factories (April 2019), representing around 55 per cent of the total volume.

Removals from natural forests are mainly in the form of firewood that is consumed at the household level and by local institutions including schools and hospitals. Small quantities are sold to tea factories. Insignificant quantities are used as timber for the manufacture of furniture and construction in the forest-adjacent communities. Removals from the woodlands are normally not properly controlled as policing of these areas is by county governments, which have inadequate law enforcement personnel. The removals are mainly in the form of charcoal wood, as evidenced by the situation in Kitui County where 260,521 bags (around 50 kilograms per bag) of charcoal were recorded between July 2016 and June 2017.

Impacts of tea Industries on forests

Sixty-eight tea factories of the Kenya Tea Development Agency use around 1 million m^3 of well-seasoned firewood per year, equivalent to 5,700,000 eucalyptus trees or 3,600 hectares of high-quality commercial tree plantations. Around 50 per cent of this wood is sourced from government commercial plantations, mainly through third parties licensed by Kenya Forest Service. The balance of 50 per cent is sourced from own factory plantations, community plantations and farmers' smallholder trees/forests (MEF 2018), farms and public plantation residues.

However, with the cessation of tree harvesting in public forests, the rate of tree harvesting on farms has increased drastically, with trees that were once considered only for firewood now being harvested for timber. As a result, the tea factories are experiencing pressure with escalating prices of wood, thus causing a majority of the factories to acquire land for their own planting as well as contracting their farmers to grow trees specifically for the factories.

Figure 4.5. Wood harvested for charcoal production in Narok County

Photo: Emily M. Kitheka (KEFRI)

Bamboo case

Currently, limited bamboo is harvested for the supply of fuelwood. However, a few tea factories around the Aberdares Ranges and Bidco Oil Company in Thika have adjusted their boilers to use bamboo as fuelwood. The use of bamboo in the construction industry is still in its infancy, so most of the bamboo that is grown can be used as firewood in the near future. The indigenous bamboo

forestry can contribute greatly to the bioenergy sector in Kenya because bamboo is a fast-growing plant that generates substantial amounts of biomass within a short period of time.

The bamboo forests, which cover 133,273 hectares nationally, are distributed in five ecosystems: Mount Elgon, Cherang'any, Mau, Aberdares Range and Mount Kenya (Zhao et al. 2018).

The estimated removable harvest from wood and bamboo resources for bioenergy use in Kenya is shown in Table 4.5.

Table 4.5. Estimated wood and bamboo resources available for bioenergy in Kenya

Forest type	Area (1 000 ha)	Average volume per ha (m^3)	Growing stock (1 000 m^3)		Net annual increment (m^3/ha/yr)		Removals (m^3/ha/ yr)	Volume removed (1 000 m^3)	% of volume removed	Available for bio-energy (1 000 m^3/yr)
	2010	2010	2010	2015	2010	2015	2015	2015	2015	2019
Natural forest	4 037	180	726 660	774 145	2.8	3.3	0.8	3 230	0.4	325.1
Public plantations	122	280	54 040	61 600	21.8	21.8	2	244	0.4	13.6
Private plantations	71	280	19 880	35 850	29.7	35	1.8	128	0.4	7.1
Woodlands	9 652	32	308 864	299 680	0.1-1.2[c]		4.9	47 295	15.8	13
*Bamboo	133	56.3[a]		8 689	2.8	3.3	6.2-13.6[a]	47	30	260.7
Mangroves	49	143[b]		7 007		8.4	0.8	39	0.4	2.9

Source: Compiled from figures in FAO 2016
[a] Muchiri and Muga 2019; [b] MENR 2017; [c] Johansson and Kaarakka 1992; [d] Lang'at et al. unpublished

4.3.5 Conclusions and recommendations

Synthesis of the findings

Because data on the harvesting of natural forest are difficult to access, the data used here are based instead on the current and projected use of wood for certain products.

The use of fuelwood for charcoal production and the tea industries is putting more pressure on farmlands.

Practices and policies to improve sustainability

The government's moratorium on harvesting of timber on all public and community forests for 90 days, in effect since 2018, has not yet shown results on the efficacy of the measure, particularly in avoiding deforestation.

Future monitoring

It is recommended that data on the harvesting of fuelwood from natural forests in different parts of the country are gathered and recorded.

Data on harvesting from private plantations needs to be updated and recorded. It is suggested to have one single depository for accessibility of the data.

4.3.6 References

Food and Agriculture Organization of the United Nations (2015). *Global Forest Resources Assessment 2015, Country Report Kenya*. Rome.

Food and Agriculture Organization of the United Nations (2016). *2016 Forest Resource Assessment Report.* Rome

Johansson, S.G. and Kaarakka, V.J. (1992). Regeneration of cleared *Acacia zanzibarica* bushland in Kenya. *Journal of Vegetation Science* 3, 401-406.

Lang'at, J.K.S., Bosire, J.O. ,Karachi, M. and Kairo, J.G. (unpublished). KMFRI and Egerton report. https://www.oceandocs.org/bitstream/handle/1834/8863/ktf00592.pdf?sequence=1&isAllowed=y.

Ministry of Environment and Forestry (2018). Task Force Report on Forest Resources Management and Logging Activities in Kenya. http://www.environment.go.ke/wp-content/uploads/2018/05/Task-Force-Report.pdf.

Ministry of Environment and Natural Resources (2016). *Kenya National Forest Programme 2016-2030*. Nairobi.

Ministry of Environment and Natural Resources (2017). *National Mangrove Ecosystem Management Plan.* Nairobi.

Ministry of Environment, Water and Natural Resources (2013). *Analysis of the Charcoal Value Chain in Kenya.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Ministry of Forestry and Wildlife (2013). *Analysis of Drivers and Underlying Causes of Forest Cover Change in the Various Forest Types of Kenya.* Consultant Report. Nairobi.

Muchiri, M. and Muga, M. (2019). *Country Profile of Climate Change Mitigation Potential of Implementing Sustainable Management for Bamboo Forest in Kenya.* A report prepared for INBAR.

OFESA (2019). Eastern Africa Forest Observatory (OFESA). State of Forests and REDD Kenya. http://apps.rcmrd.org/ofesa/en/state-of-forests-and-redd/kenya.

SLEEK (2018). *Key Decisions and Designs.* Ministry of Forestry and Natural Resources. Nairobi.

WWF (2019). Kenya Deforestation Hotspots Map. https://www.wwfkenya.org/keep_kenya_breathing_/state_of_forest_in_kenya/. Accessed September 2019.

Zhao, Y., Feng, D., Jayaraman, D., Belay, D., Sebrala, H., Ngugi, J., Maina, E. et al. (2018). Bamboo mapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery. *International Journal of Applied Earth Observation and Geoinformation* 66, 116-125. doi:10.1016/j.jag.2017.11.08.

4.4 Indicator 4. Emissions of non-greenhouse gas air pollutants, including air toxics

4.4.1 Definition

(4.1) Emissions of non-greenhouse gas air pollutants, including air toxics, from 1) feedstock production, 2) processing, 3) transport of feedstocks, intermediate products and end products, and 4) use; and comparisons with other energy sources.

4.4.2 Measurement unit(s)

Emissions of particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides, sulphur dioxide and other pollutants in 1) milligrams per hectare (mg/ha), milligrams per megajoule (mg/MJ) and as a percentage; 2) milligrams per cubic metre (mg/m^3) or parts per million (ppm); 3) mg/MJ; 4) mg/MJ

4.4.3 Overall methodology of the implementation

The methodology follows the same assumptions as in Indicator 1. In the case of the use of sugarcane bagasse briquettes in tea factories, it was assumed that the use of firewood was common practice in the tea industry (reference scenario) and that sugarcane bagasse briquettes were used as an alternative (improved scenario). Information was obtained from literature review, field visits and the Global Bioenergy Partnership tool. The life cycles in this pathway considered emissions of sulphur dioxide, nitrogen oxides, carbon monoxide and particulate matter 10 (PM_{10}).

A literature review was carried out on the use of sugarcane bagasse briquettes and firewood in the tea industry in Kenya and on emissions of non-greenhouse gas air pollutants along their life cycles. Primary data were gathered through visits to sugarcane bagasse briquette production plants and tea factories.

4.4.4 Key findings

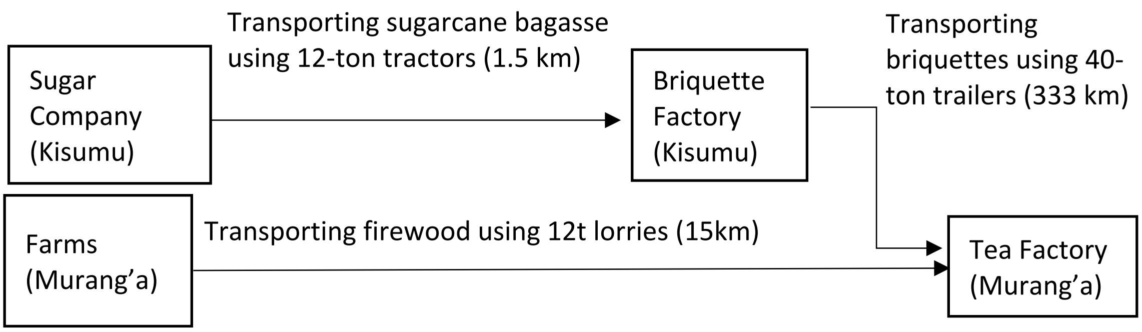
BAGASSE BRIQUETTES

Assumptions

As illustrated in Figure 4.6, the life cycle stages of sugarcane bagasse briquettes that were considered include: 1) transport of the sugarcane bagasse from sugar factories in Kibos, Kisumu County for 1.5 kilometres to the briquette plant using a 12-ton tractor, 2) production of the bagasse briquettes, 3) transport of the briquettes for 333 kilometres to tea factories in Murang'a County using a 40-ton trailer that returns empty (hence emissions are based on two-way transport at 666 kilometres) and firewood from small-scale tea farms within the factories' catchment radius of 15 kilometres (30 kilometres two ways) using 12-ton trucks, and 4) use of sugarcane bagasse briquettes and firewood in the tea factories.

The sugar factory delivers the sugarcane bagasse to the briquette plant using its own tractors of between 6 and 7 tons. However, the GBEP database lacked information on 6-7 ton trucks; hence a 12-ton truck was adopted. Likewise, 12 ton and 22 ton trailers were used in transporting the sugarcane bagasse briquettes, but the GBEP tool lacked data on these tonnages and hence information on a 40-ton truck was applied. The tea factory under study uses 2 m^3 of firewood (equivalent to 1,100 kilograms as 1 m^3 = 550 kg according to Kenya Tea Development Agency) and 45 kilograms of briquettes per hour in its boilers.

Figure 4.6. Stages that were studied in use of sugarcane bagasse briquettes and firewood in tea factories



Results

Data on emissions from the use of the sugarcane bagasse briquette and firewood in the tea factories were unavailable and hence data in the GBEP tool were adopted in this computation. In addition, data on some of the sizes of the vehicles used locally were missing.

In reference to firewood, the use of sugarcane bagasse briquettes could lead to a 3.7 per cent increase in sulphur dioxide, a 31.9 per cent increase in nitrogen oxides, a 4.2 per cent increase in carbon monoxide, and a 2.8 per cent increase in PM_{10}.

Figure 4.7. Sulphur dioxide emissions

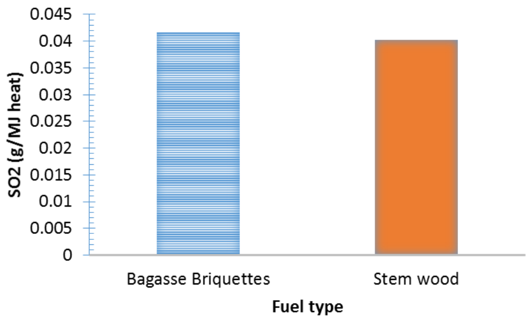


Figure 4.8. Nitrogen oxide emissions

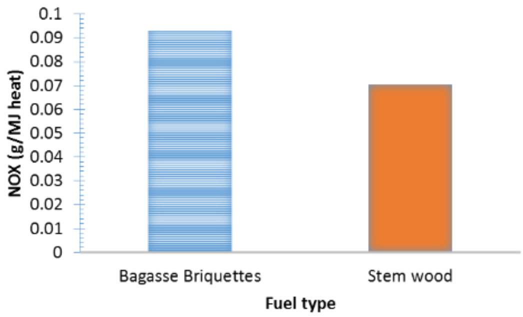


Figure 4.9. Carbon monoxide emissions

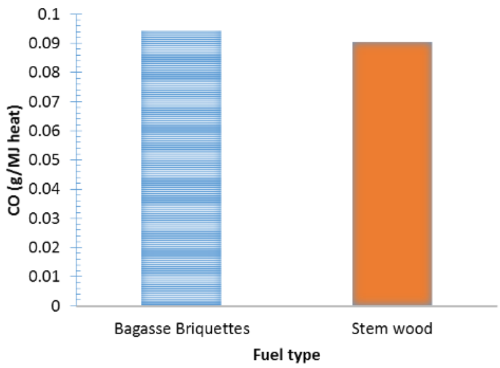
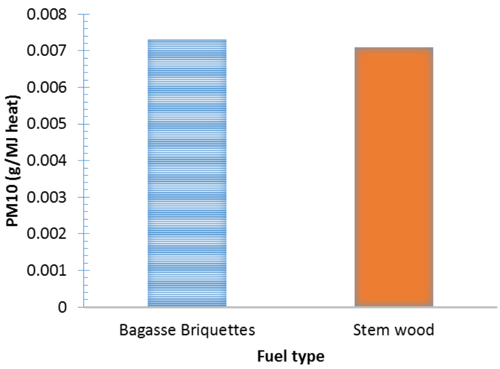


Figure 4.10. PM_{10} emissions



The emissions for each stage of the pathway and the totals from both the improved and reference scenarios are shown in Table 4.6.

Table 4.6. Emissions per stage in the pathway

Gases/Particles (g/MJ) Improved scenario	Transport	Processing	Use	Total (improved scenario)	Total (reference scenario)
Sulphur dioxide	0.0019	0	0.0398	0.0417	0.0402
Nitrogen oxides	0.0267	0	0.0662	0.0930	0.0705
Carbon monoxide	0.0047	0	0.0894	0.0942	0.0904
PM_{10}	0.0004	0	0.0070	0.0073	0.0071

Interpretation as regards to sustainability

The use of sugarcane bagasse briquettes as an alternative to firewood in the tea factories located far from briquetting plants poses sustainability challenges due to high emissions resulting from the use of fossil fuels in transport. This is because firewood used by tea factories is sourced from farmers within their catchments, which involves shorter distances and hence emissions reduction. However, where trees were harvested without replanting or management plans, firewood would be unsustainable as carbon sinks would be removed from the landscape.

CHARCOAL

Assumptions

For charcoal, the assessment considered charcoal production using fresh wood with a 50 per cent moisture content, sourced from woodlands and farmlands, with 90 per cent of the charcoal producers using traditional kilns and 10 per cent using improved kilns. The charcoal is then transported from Kitui to Nairobi (350 kilometres) and from Narok to Nairobi (284 kilometres) using trucks that purposely travel for charcoal (two-way {SN2}-reference scenario). The charcoal is used by households in Nairobi in both traditional stoves (metal Jiko; 62 per cent of users conventionally) and improved stoves (Kenya Ceramic Jiko; 38 per cent of users).

An alternative system is also considered, in which wood is air dried to 20 per cent moisture content, and 20 per cent of charcoal producers use traditional kilns and 80 per cent use improved kilns. The charcoal is then transported from Kitui to Nairobi (175 kilometres) and from Narok to Nairobi (142 kilometres) using trucks that carry charcoal one way {SN1}-improved system), and 20 per cent of households use charcoal with traditional stoves and 80 per cent use improved stoves. The performance of the improved system is compared with the conventional/common practice.

The first stage considers the production and harvesting of trees from native woodlands in farmlands in Kitui and Narok counties. Kitui and Narok counties are among the main sources of charcoal used in Nairobi (MEWNR 2013a). These two counties have acacia tree species, which are preferred for their high-quality charcoal (Mugo and Ong 2006; Mutimba and Barasa 2005; Giathi et al. 2016). Other sources of trees are the residue resulting from land clearing for crop production (wheat {*Triticum}* and maize *{Zea mays}*) in Narok (Mutimba and Barasa, 2005). Calculation of emissions in this stage excluded wood production and only considered mechanized harvesting of wood using chain saws (power saws) that are powered using fossil fuels and assumed to be used by 20 per cent of charcoal producers. Transport of harvested wood to the carbonization sites is normally carried out manually.

The second stage includes the emissions resulting from the wood-to-charcoal carbonization process using kilns. Ninety-nine per cent of charcoal producers use traditional earth-mound kilns with a low efficiency of 10-14 per cent in converting wood into charcoal (MEWNR 2013b, Okello et al. 2001; Mutimba and Barasa 2005) versus improved earth kilns with 30 per cent charcoal yield efficiency used by the rest of the charcoal producers (Bailis 2009). In this study, 15 per cent charcoal yield efficiency was adopted for the traditional kiln and 30 per cent for the improved kiln. For carbonization using traditional kilns, wood is rarely dried hence fresh wood with a moisture content of around 50 per cent is used. In improved kilns, the wood is first air-dried for several days, and the moisture content reduces to around 20 per cent. Produced charcoal is packed in recycled sacks weighing around 35 kilograms (MEWNR 2013b).

The third stage is the calculation of emissions during transport of the charcoal from charcoal production areas to Nairobi city, where 82 per cent of the households use charcoal (MoE 2002). In this study Kitui and Narok counties, which are around 175 kilometres and 142 kilometres from Nairobi respectively (Google estimates), are considered as the sources of charcoal. From the production site, the charcoal is transported with motorbikes, bicycles, donkey carts, and on people’s

backs or heads to a central point along the main road. From these points charcoal is then transported using 12-ton trucks. The conventional (reference) transport practice is the trucks going purposely to collect the charcoal from Kitui and Narok (referred to as SN2 hereafter). In the alternative (improved) system, the trucks ferry goods to the charcoal production sites and carry charcoal on their way back to Nairobi (referred to as SN1).

The fourth stage considers emissions first from the conventional practice, in which urban households use a mix of the traditional stove (62 per cent) and the improved stove (38 per cent). This was compared to an improved system where households use a mix of the traditional stove (20 per cent) and the improved stove (80 per cent). The traditional metal stove {Jiko} has 10-15 per cent energy conversion efficiency (15 per cent adopted for this study), while the KCJ has a conversion efficiency of around 33-35 per cent (33 per cent adopted for this study) (Mugo et al. 2007; GBEP tool).

Data from the year 2018 were excluded due to the effect of the logging ban, which influenced charcoal production and transport.

Data on the transport of charcoal from the production sites to the collection areas in the counties were excluded, as data on emissions from the locally used modes of transport such as motorbikes are not available.

Results

In reference to the conventional/common practice (SN2), the alternative/improved practice (SN1) could result in a reduction of gases and particle emissions from charcoal production, transport and use, as shown in Table 4.7. The emissions for each stage of the pathway in the improved system are shown in Table 4.8. The variation was caused by changes in the distance of transport.

Table 4.7. Emission reduction by improved system of charcoal production and transport from Kitui and Narok and use in Nairobi, Kenya in absolute units and percentage

Gas/particle (g/MJ)	Kitui			Narok		
	SN2	absolute SN1*	% reduction	SN2	absolute SN1*	% reduction
Sulphur dioxide	0.0017	0.0008	47	0.0014	0.0007	50
Nitrogen oxides	0.0312	0.0101	33	0.0273	0.0081	30
Carbon monoxide	12.0368	0.0023	0.02	12.0359	0.0019	0.02
PM_{10}	0.0826	0.0003	0.38	0.0825	0.0003	0.36

*Reduction in SN1 in absolute units

Table 4.8. Emissions per stage in the pathway from the improved system

Gases/Particles (g/MJ)	Kitui SN1			Narok SN1		
	Transport	Processing	Use	Transport	Processing	Use
Sulphur dioxide	0.00084	0.00003	0.00003	0.00067	0.00003	0.00003
Nitrogen oxides	0.01008	0.00197	0.00578	0.00813	0.00197	0.00578
Carbon monoxide	0.00231	6.96875	5.06250	0.00186	6.96875	5.06250
PM_{10}	0.00031	0.01563	0.06625	0.00025	0.01563	0.06625

Interpretation as regards to sustainability

All the gases and particle emissions are reduced by shifting from: 1) using fresh wood with around 50 per cent moisture content to air-drying wood to 20 per cent moisture content, 2) low to high adoption of improved kilns (from 10 per cent to 80 per cent) and stoves (38 per cent to 80 per cent) and 3) reducing distance in transport from two way to one way, where trucks ferry goods to the charcoal production sites and carry charcoal to the city on their way back.

4.4.5 Conclusions and recommendations

Synthesis of the findings

The replacement of firewood with sugarcane bagasse briquettes, transported from Kisumu by the tea factory at Murang'a, increases the emissions of sulphur dioxide by 3.7 per cent, nitrogen oxides by 31.9 per cent, carbon monoxide by 4.2 per cent and PM_{10} by 2.8 per cent. This could mainly be caused by the use of fossil fuel in the transport of the bioenergy resource. To reduce the emissions from briquette transport and the costs incurred, there is a need to assess the availability of briquette-making biomass feedstock resources and to establish briquette plants near points of use. As the boiler systems were designed for firewood use, there is a need for studies to assess boiler performance using sugarcane bagasse briquettes and for subsequent modifications to be made as necessary.

Regarding charcoal, although this was excluded for the calculation of emissions in this study, sustainable production of wood should be ensured, whereby tree replanting, harvesting of mature stems and leaving others to grow, as well as management of natural regeneration is ensured for continuous biomass stands. This should be integrated with improved technologies on drying wood properly, kilns and stoves. This can be enhanced through the engagement of end users in technology development, capacity development and incentives including tax reductions. In addition, higher adoption of improved technologies in carbonizing wood into charcoal and use, integrated with reduced distance covered in transporting charcoal by accounting for one way travel, have benefits in reducing emissions.

There is therefore a need for capacity development, the use of incentives and tax reduction or elimination for enhanced adoption of the improved production and use technologies. Participation of the charcoal producers and users in the design and development of improved kilns and stoves is critical to ensure that their needs and preferences are taken into consideration. The improved system on one-way charcoal transport (SN1) should be adopted as much as possible to reduce emissions.

Practices and policies to improve sustainability

Sugarcane bagasse briquettes are preferred by tea factories as they burn more consistently compared to firewood, hence maintaining the flow of steam into the boilers with minimal temperature fluctuations. However, the briquettes present the challenge of forming clinkers/ashes in the boiler tubes, necessitating frequent unclogging which interferes with the running of the boilers. Further boiler systems are designed to use firewood and hence there is a need for modification to efficiently burn briquettes. Furthermore, there is a need for quality control of the sugarcane bagasse briquettes, as those made from fresh bagasse exhibit better burning properties than those produced from decomposing bagasse. With regard to operations, loading of briquettes into boilers needs to be mechanized to increase loading per given time hence reducing the frequency of opening the door which disrupts combustion, causing fluctuations in temperature and consequently affecting the steam flow. There is also a need to monitor emissions from the use of biomass energy to assess the efficiency of the boilers and identify areas for improvement.

For sustainable charcoal production in Kenya, tree management and replanting plans through a variety of contextualized agroforestry systems is critical, integrated with improved kilns and stoves and reduced distance in the transport of charcoal. Wood grown on farms for charcoal production should be sustainably managed by harvesting the mature stems and leaving the young ones to continue growing for consecutive harvesting, ensuring continuous standing biomass as carbon sinks. Trees that coppice well and naturally regenerate should be promoted for charcoal production, and suitable species should be used for the different agro-climate zones in Kenya as recommended by

Njenga et al. (2014). Because adoption of these improved systems has been a challenge, incentives for their adoption should be put in place.

Future monitoring

Regarding bagasse briquettes, data were missing on the emissions of non-greenhouse gas air pollutants from combustion in the tea factories. Studies should be conducted to find out the best mixing ratio of the firewood and briquettes to reduce the formation of clinkers/ashes and emissions of non-greenhouse gas air pollutants, and to enhance combustion efficiency. Mapping of potential resources for briquette production is also required to reduce the transport distance of the end product.

For charcoal, data on the various means used to transport the charcoal from the production sites to the central points before transport to Nairobi need to be gathered for consequent work. Data on the mechanization of wood harvesting also need to be compiled, as well as on the emissions associated with those activities. The emission factors of the locally used motorbikes, trucks/lorries used to transport the charcoal from the charcoal production areas to the capital centre also need to be gathered. Future work should integrate the wood production systems for charcoal production to assess sustainability at this stage of the life cycle.

4.4.6 References

Bailis, R. (2009). Modeling climate change mitigation from alternative methods of charcoal production in Kenya. *Biomass and Bioenergy*, 33(11). 1491–1502. DOI:10.1016/j.biombioe.2009.07.001

Giathi, G., Kitheka, E., Kiama, S., Sheikh, M., Bala, P., Githiomi, J., Oduor, N. et al. (2016). *Tree Species Composition and Diversity in Areas of High Charcoal Production in Kitui County: A Case in Ikutha and Mwingi sub-Counties*.

Ministry of Energy (2002). *Republic of KENYA Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small-scale Industries and Service Establishments*. Final report. Nairobi. P. 160.

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of Demand and Supply of Wood Products in Kenya Study*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%2Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Ministry of Environment, Water and Natural Resources (2013b). *Analysis of the Charcoal Value Chain in Kenya.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Mugo, F., Nungo, R., Odongo, F., Chavangi, N. and Abaru, M. (2007). *An Assessment of the Energy Saving Potential and Heat Loss Pattern in Fireless Cooking for Selected Commonly Foods in Kenya.* CARPA Working Paper Series No. 2.

Mugo, F. and Ong, C. (2006). *Lessons of Eastern Africa's Unsustainable Charcoal Trade*. ICRAF Working Paper no. 20. World Agroforestry Centre. Nairobi.

Mutimba, S. and Barasa, M. (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainable Charcoal Industry in Kenya.* Energy for Sustainable Development Africa.

Njenga, M., Karanja, N., Karlsson, H., Jamnadass, R., Iiyama, M., Kithinji, J. and Sundberg, C. (2014). Additional cooking fuel supply and reduced global warming potential from recycling charcoal dust

into charcoal briquette in Kenya. *Journal of Cleaner Production.* 81-88. 10.1016/j.jclepro.2014.06.002.

Okello, B.D., O'Connor, T.G. and Young, T.P. (2001). Growth, biomass estimates, and charcoal production of *Acacia drepanolobium* in Laikipia, Kenya. *For. Ecol. Manag.* 142, 143-153.

4.5 Indicator 5. Water use and efficiency

4.5.1 Definition

(5.1) Water withdrawn from nationally determined watershed(s) for the production and processing of bioenergy feedstock, expressed

(5.1a) as the percentage of total actual renewable water resources (TARWR) and

(5.1b) as the percentage of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources;

(5.2) Volume of water withdrawn from nationally determined watershed(s) used for the production and processing of bioenergy feedstock per unit of bioenergy output, disaggregated into renewable and non-renewable water sources.

4.5.2 Measurement unit(s)

(5.1a) percentage, (5.1b) percentage, (5.2) m^3/MJ or m^3/kWh, or m^3/ton for feedstock production phase if considered separately.

4.5.3 Overall methodology of the implementation

The testing of Indicator 5 in Kenya began with a determination of the current situation related to water supply, demand and uses, and with characterizations of water basins in the country. Data on total annual water withdrawals (TAWW) are not available for the country. Rather than water withdrawal, Kenya provides these data as water demand, which is slightly different. This will be modified to represent TAWW.

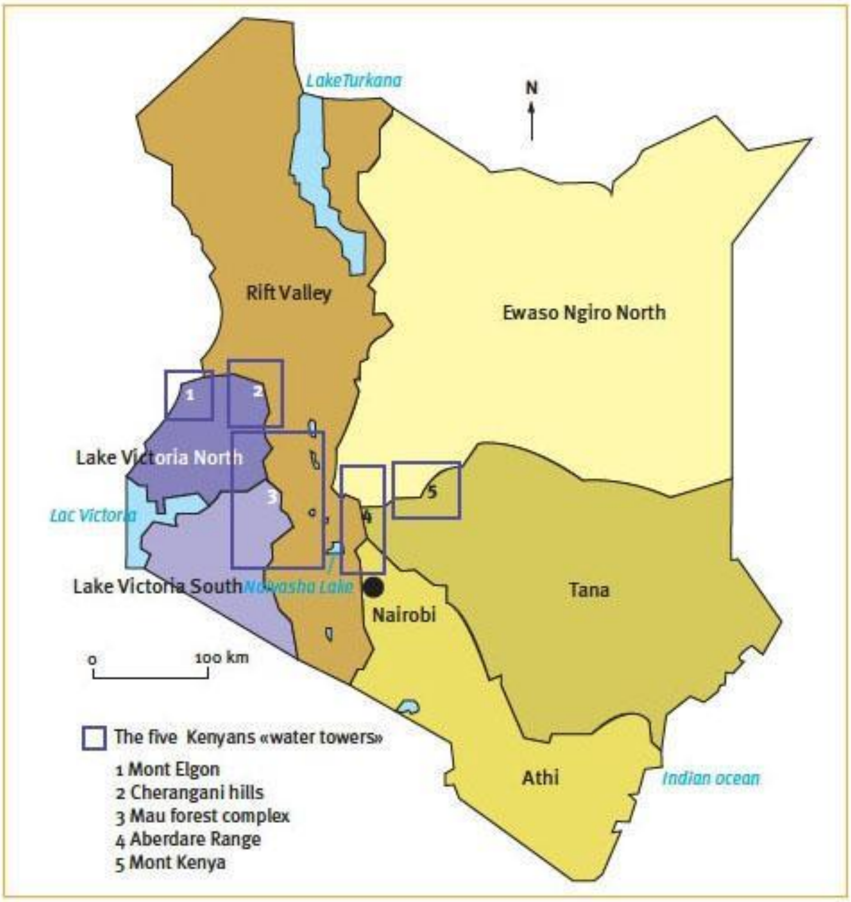
Two watersheds within which key feedstock (bagasse) are produced – Lake Victoria South Catchment Area and Lake Victoria North Catchment Area **–** were delineated from the larger watersheds. Water resources were estimated using FAO AQUASTAT, whereas water use and demand data were collected through secondary sources.

4.5.4 Key findings

According to the Water Resources Management Authority (2016), there are six main catchments in the country used as units for water resources management: Lake Victoria North Catchment Area, covering 3.0 per cent of the country; Lake Victoria South Catchment Area, covering 5.0 per cent; Rift Valley Catchment Area, which includes the inland lakes, covering 22.5 per cent; Athi Catchment Area stretching up to the coast, covering 11.5 per cent; Tana Catchment Area, covering 21.7 per cent; and Ewaso Ng'iro North Catchment Area, covering 36.3 per cent (FAO 2014) (Map 4.6).

The water distribution in the drainage basins is uneven, with, for example, 282 600 m^3/ km^2 or over 750 m^3/year per capita in Lake Victoria basin, and 21 300 m^3/km^2 or 162 m^3/year per capita in the Athi Catchment (WRMA 2018).

Map 4.6. Large catchments and main water towers of Kenya



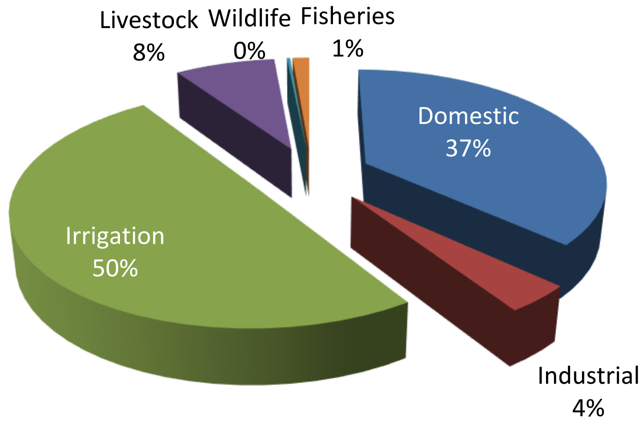
Source: Adapted from Rouillé et al. 2015

Table 4.9. Area and consumption of Kenya's main water catchments, 2010 and projections for 2030 and 2050

Catchment area	Area (km²)	2010 (million m³/yr)	2030 (million m³/yr)	2050 (million m³/yr)
Lake Victoria North Catchment Area	18 374	4 742	5 077	5 595
Lake Victoria South Catchment Area	31 734	4 976	5 937	7 195
Rift Valley Catchment Area	130 452	2 559	3 147	3 903
Athi Catchment Area	58 639	1 503	1 634	2 043
Tana Catchment Area	126 026	6 533	7 828	7 891
Ewaso Ng'iro North Catchment Area	210 226	2 251	3 011	1 810
TOTAL	575 451	22 564	26 634	28 437

Source: GoK 2013.

Figure 4.11. Water demand by subsector



Source: GoK 2013

In 2010, agriculture and domestic use accounted for most of the total annual water withdrawal (TAWW) at 87 per cent, followed by livestock (8 per cent), industry (4 per cent) and wildlife and fisheries (1 per cent) (FAO AQUASTAT 2015). The total annual renewable surface (TARWR) water in 2010 was estimated at 20.637 km^3/year, while the sustainable yield of groundwater was 1.927 km^3/year using a sustainable groundwater use of 10 per cent of recharge; thus, the total available water resources was estimated as 22.564 km^3/year in 2010 (GoK 2013). This is 586 m^3/yr per capita based on the 2010 population. Kenya is therefore a water-scarce country compared to its neighbours Uganda and Tanzania at 2,940 m^3 and 2,696 m^3 per year respectively, and also way below the international water per capita benchmark of 1,000 m^3/yr.

Using projected future climate scenarios, the National Water Master Plan (NWMP) 2030 study showed that the renewable surface water resources will increase from 20.64 km^3/year in 2010 to 24.89 km^3/year in 2030, and the sustainable yield of groundwater will decrease from 1.93 km^3/year to 1.74 km^3/year due to the combined effect of increased precipitation and evapotranspiration, especially in the arid and semi-arid land areas. The NWMP 2030 study indicates that the estimated total water demand will increase from 3.218 km^3/year to 21.468 km^3/year over the same period (GoK 2013); this includes a demand of 0.114 km^3/year in 2010 and 0.714 km^3/year in 2030 to be supplied by water from international rivers draining into Kenya.

According to FAO AQUASTAT (2015), internal renewable surface water resources are estimated at 19 200 million m^3/year and renewable groundwater resources at around 3,500 million m^3/year, but 3,000 million m^3/year is considered to be overlap between surface water and groundwater, which gives a value of total internal renewable water resources (IRWR) of 20,700 million m^3/year.

According to the Kenya Sugar Directoriate (2019) the total area under sugar cane cultivation was 220,997 hectares with average yield being 60.55 tons of cane per hectare. In Kenya, sugarcane cultivation is rainfed, therefore, water consumption for its cultivation is mainly from green water. Water consumption (rainfed) for sugarcane cultivation is around 10.5 m^3/day per hectare or 3,832 m^3/year per hectare. The current water use efficiency ranges from 5.2 to 8.9 tons/ha/millilitre, which is low due to the low rainfall use efficiency.

4.5.5 Conclusions and recommendations

Synthesis of the findings

Kenya is a chronically water-scarce country at 586 m^3/yr per capita against the international benchmark of 1,000 m^3/yr. Total water demand will increase from 3.218 km^3/year to 21.468 km^3/year from 2010 to 2030. This means that the country will be walking on a tight rope as demand will probably equal or surpass available water resources.

Practices and policies to improve sustainability

Most sugarcane bagasse lies in piles across most of the sugar industries. The existence of a small number of briquette-making companies coupled by the cost of transporting bagasse to the nearest briquetting companies is prohibitive and is associated with the low uptake of briquettes as a bioenergy source.

The Kenyan government encourages the uptake of renewable energy sources through the Kenya Energy Act 2019, making the policy environment for briquettes favourable. The formation of an umbrella briquette manufacturers association would present an opportunity to lobby for increased uptake of bioenergy sources to the government, users and stakeholders. Increasing the market for briquettes is an important step towards their adoption. This can be achieved through campaigns that would encourage the use of briquette-compatible stoves and awareness creation on clean energy.

Future monitoring

Because the production of briquettes from bagasse is relatively new, data are limited. As the bioenergy sector continues to expand in Kenya, monitoring of Indicator 5 in key watersheds with significant levels of bioenergy feedstock cultivation and processing will be crucial. This should involve actual data collection on the use of water needed to produce and use briquettes. Further information involved in the charcoal pathway should be reviewed through actual field practices.

4.5.6 References

FAO AQUASTAT (2015). Food and Agriculture Organization of the United Nations. http://www.fao.org/nr/water/aquastat/countries_regions/KEN/. Accessed March 2019.

FAO (2014). Country Programming Framework For Kenya 2014-2017. Food and Agriculture Programme http://www.fao.org/3/a-bp634e.pdf

Government of Kenya (2013). The Project on the Development of the National Water Master Plan 2013 Final Report. https://wasreb.go.ke/national-water-master-plan-2030/

Kenya Sugar Directoriate (2019). Agriculture and Food Authority. https://sugar.agricultureauthority.go.ke

Rouillé, G., Blanchon, D., Calas, B. and Temple-Boyer, É. (2015). Environnement, écologisation du politique et territorialisations : les nouvelles politiques de l'eau (gire et pse) au Kenya. L'Espace Géographique 44(2), 131-146.

Water Resources Management Authority (2013). *The National Water Master Plan 2030. Volume V. Sectoral Report (E) Agriculture and Irrigation.* Nairobi.

4.6 Indicator 6. Water quality

4.6.1 Definition

(6.1) Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for bioenergy feedstock production, and expressed as a percentage of pollutant loadings from total agricultural production in the watershed
(6.2) Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents in the watershed

4.6.2 Measurement unit(s)

(6.1) Annual nitrogen (N) and phosphorus (P) loadings from fertilizer and pesticide active ingredient loading attributable to bioenergy feedstock production (per watershed area): in kg of N, P and active ingredient per hectares per year
(6.2) Pollutant loadings attributable to bioenergy processing effluent: pollutant levels in bioenergy processing effluent in mg/litre.

4.6.3 Methodology

The indicator was assessed using literature review and analysing selected water quality parameters in the main catchment areas in Kenya that are impacted by agriculture and forestry.

4.6.4 Key findings

Results from literature assessment show that large quantities of pollutants are entering surface and ground water bodies. However, there are no data attributable to briquette processing and charcoal production relating to lowered water quality. Pesticide application data for sugarcane farming were not available to allow disaggregation from larger agricultural activities contributing to pollution. Further, wastewater from the Kenyan tea industry is usually allowed into pools through open channels that lead to pollution of water bodies around the factories. Results from literature assessments show that levels of biochemical oxygen demand and chemical oxygen demand exceeded the maximum allowable discharge limits by the Kenya National Environmental Management Authority standards.

Clearing of forest cover for charcoal production in the country increases soil erosion. The eroded material from soil and remnants of charcoal production moves downstream causing sedimentation and siltation into waterways. The degraded forested catchments further facilitate the increased velocity of flowing water resulting in more erosion hence more sediment and silt downstream. As turbidity and sediment load increase downstream, the quality of receiving water is lowered (MENR 2016). Habitat modification through charcoal burning results in non-point pollution as degraded areas become prone to erosion. These areas are marked by reduced infiltration, erosion and siltation which degrade water bodies.

The briquettes in focus are made from bagasse, a by-product of sugarcane processing. Most of the sugar mills have no installed capacity to process briquettes. The bagasse backlog is stacked in their yards before it finds its way to briquetting. In most mills there are no impervious bases where bagasse is stored to direct the effluent to treatment. Water pollution is caused by run-off from these bagasse piles (Purchase et al. 2013).

A report by the Water Resources Management Authority (WRMA 2018) indicated that 86 per cent of 260 surface water quality monitoring stations were monitored for the year 2018. A national average of 60 per cent compliance with ambient water quality standards was registered. Regionally, the Lake Victoria South Catchment Area mean was the highest at 96 per cent, and the lowest was Lake

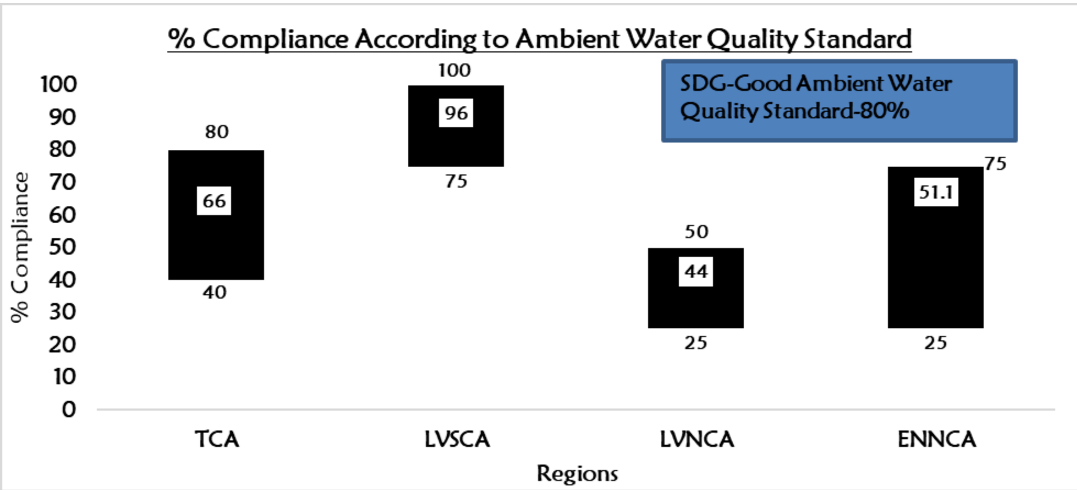
Victoria North Catchment Area at 44 per cent. In terms of compliance with the Sustainable Development Goal (SDG) 6.3 target of 80 per cent good ambient water quality, only the Lake Victoria South Catchment Area had 85 per cent of its stations achieve this. The major parameter contributing to the poor national performance towards the SDG target was high total phosphorous levels, which were attributed to the heavy use of phosphate fertilizers in all of the six catchments (WRMA 2018).

For point-source pollution, a total of 102 data points were collected, with the majority from the Lake Victoria North Catchment Area at 56 per cent. Effluent dischargers were assessed for their compliance with effluent discharge standards as per Schedule 3 of the Water Resources Management Rules 2007. From the assessment, the national mean was 46.7 per cent compliance with these standards. Regionally, Ewaso Ngiro North Catchment Area and Lake Victoria South Catchment Area had the highest and lowest compliance at 61.1 per cent and 36.1 per cent respectively. Chemical oxygen demand was the least complied-with parameter, at 14 per cent (WRMA 2018).

For non-point pollution, assessment was done by compiling the proportion of the parameter that complied with the standards for effluent discharge into water resources as per Schedule 3 of the Water Resources Management Rules 2007. A region's performance was calculated as the average of the compliance of its effluent dischargers. A minimum of four parameters was required for these calculations. Only Ewaso Ngiro North Catchment Area, Lake Victoria South Catchment Area and Lake Victoria North Catchment Area met this criterion, where pH, total dissolved solids, total suspended solids, total phosphorous, biochemical oxygen demand and chemical oxygen demand were analysed. Athi Catchment Area and Tana Catchment Area had only one station monitored, with only pH and total dissolved solids measured.

The results (Figure 4.12) showed that pollution in the assessed water points was common across the six catchments. The figure shows the ranges and mean performance (white values) in compliance with ambient water quality standards of stations in each region. The maximum values are on the top and the minimum values on the bottom. The Lake Victoria South Catchment Area and the Lake Victoria North Catchment Area, where sugar cane growing is common, had higher pollutants, probably due to the high volume of fertiliser use.

Figure 4.12. Compliance with water quality standard by catchment area



Source: WRA 2018

As shown in Table 4.10, only two sugar companies (Butali and West Sugar) were monitored in Lake Victoria North Catchment Area and Lake Victoria South Catchment Area. These were the two worst performers nationally for chemical oxygen demand at 96 per cent.

Table 4.10. Point source effluent monitoring of key sectors

Effluent categories	Average (%)	Highest	Lowest	Parameters performance	
				Best	Worst
Sugar	83.3	Butali and West Sugar companies (88.3%)		pH, total suspended solids, total dissolved solids, total phosphorus, biochemical oxygen demand (100%)	chemical oxygen demand (96%)
Municipal	41.7	Bidii wastewater treatment plant (66.7%)	Machinjoni, ELDOWAS-Boundary, Kapsabet (33.3%)	pH and total dissolved solids (100%)	chemical oxygen demand and biochemical oxygen demand (0%)
Dairy	27.1	Moi Bridge (33.3%)	KCC-Kitale (16.7%)	total dissolved solids (100%)	chemical oxygen demand, total suspended solids, total phosphorus, biochemical oxygen demand (0%)
Flower	54.7	Zena Roses-Asai Farm and Equator Flowers (66.7%)	Maji Mazuri Flower (33.3%)	total dissolved solids (100%)	chemical oxygen demand (0%)

Source: WRMA 2018

4.6.5 Conclusions and recommendations

Synthesis of the findings

The generation of industrial solid waste such as bagasse is a global concern. Improper storage and disposal of these wastes lead to environmental pollution and contamination. Bagasse heaping have a negative impact on water quality through its acidification and eutrophication potential as well as photochemical oxidant creation (Kiatkittipong et al. 2009).

Approximately 25-30 per cent of sugarcane crushing results in the by-product bagasse. The sugar processing industry and other associated production areas generate a large quantity of wastewater at all stages. A large amount of organic and inorganic pollutants from gaseous, liquid and solid wastes are released to the surrounding environment.

Various environmental concerns have arisen from by-products of the sugar industry. For example, vinasse, the liquid fraction generated from the rectification and distillation operations of ethanol, is a sulphur-rich, low pH, dark-colourised and odorous effluent (Rodriguez and Hu 2017). Without reprocessing, open dumping of wastes from the sugar industry, such as bagasse, has a significant impact on the environment.

Practices and policies to improve sustainability

Sugar mills can explore a number of alternatives to manage the bagasse stock heaped at factories. Apart from briquetting, the bagasse can be used for bioenergy fuel production by converting it into biogas, and for electricity production to run the sugar mills.

Future monitoring

The main issue faced in testing Indicator 6 in Kenya was the large existing data gaps. The bioenergy sector, especially briquette making, is relatively young and no work has been done that can be used

as a reference point to quantify the biochemical and chemical pollutants that emanate from this process. This was also the case for the charcoal production pathway in the two Kenyan counties. It is proposed that future field research and monitoring activities should be carried out to assess the true extent of the indicator based on the selected pathways.

The quality of the effluent discharged from Kenya's sugar and tea industries is monitored twice a year by regulation agencies. However, the number of mills whose effluent is monitored is very low, and the polluting effluent cannot always be attributed to briquette making or to the tea industry.

Investigating the impact of charcoal and briquette production on water quality is not highly prioritized in Kenya. Linking charcoal/briquette production with other sectors that are monitored for effluent discharge would provide data for future monitoring. Conclusive assessments should be done for the charcoal and briquette pathways to ascertain the full extent of their impact on water quality.

4.6.6 References

Kiatkittipong, A.U., Wongsuchoto, W. and Pavasant, P. (2009). Life cycle assessment of bagasse waste management options. *Waste Management* 29(2), 1628-1633.

Ministry of Environment and Natural Resources (2016). National Forest Programme of Kenya. Nairobi.

Purchase, B.S., Rosettenstein, S. and Bezuidenhoudt, D.V. (2013). Challenges and potential solutions for storage of large quantities of bagasse for power generation. *Proceedings of the South African Sugar Technologists' Association* 6, 495-513.

Rodrigues Reis, C.E. and Hu, B. (2017). Vinasse from sugarcane ethanol production: Better treatment or better utilization? *Frontiers in Energy Research* 5, 7.

Water Resources Authority (2018). *Water Resources Situation Report: July 2017 to June 2018*. Nairobi. https://wra.go.ke/wp-content/uploads/2019/07/National-Water-Situation-Report_2017-18.pdf.

4.7 Indicator 7. Biological diversity in the landscape

4.7.1 Definition

(7.1) Area and percentage of nationally recognized areas of high biodiversity value or critical ecosystems converted to bioenergy production;
(7.2) Area and percentage of the land used for bioenergy production where nationally recognized invasive species, by risk category, are cultivated;
(7.3) Area and percentage of the land used for bioenergy production where nationally recognized conservation methods are used.

4.7.2 Measurement unit(s)

Absolute areas in hectares or km^2 for each component and for total area used for bioenergy production. Percentage of bioenergy production area can be calculated from these and given either separately for each relevant category (i.e., different types of priority areas for 7.1 and 7.2, and specific methods for 7.3) or as a combined total across such categories.

4.7.3 Overall methodology

The literature was searched for this biodiversity indicator in Kenya. In the context of the GBEP indicator definition, areas under forest cover that are designated as game parks, game reserves and

conservancies were found to be the most relevant with regard to sub-indicator 7.1. Although forests and wildlife conservation areas in Kenya are under government protection and are supposed to be maintained as such, isolated studies revealed the changing of forests and woodlands into agriculture lands as well as localized endangering of some indigenous species. However, the Kenyan scenario does not reveal a clear national status that strictly adheres to this criteria. Opportunities exist for future documentation of forest and wildlife conservation areas that may be converted to other land use, including bioenergy production.

The Kenya National Diversity Atlas was found to be somehow useful for proving insights on national species endemism and general species status. However, this atlas it too coarse to provide meaningful results. There was no published literature with relevance to sub-indicators 7.2 and 7.3 at the national scale.

4.7.4 Key findings

NATIONAL LEVEL

There was no information meeting the criteria of this GBEP indicator as Kenya does not have areas that are specifically dedicated to bioenergy production or to cultivation of invasive alien species; therefore sub-indicator 7.3 also does not apply.

However, available information revealed that Kenya is a biodiverse country with around 25,000 recorded animal species and 7,000 recorded plant species, along with at least 2,000 fungi and bacteria. An enormous number of plant and animal species inhabit the country's varied habitats, which include coral reefs, savannas, mountains and alpine moorlands, among others. Nevertheless, this biodiversity is under threat of natural and anthropogenic effects (GoK 2015) at the species level and not necessary at the spatial level.

The National Forest Program estimates forest cover at 6.99 per cent of the total area (MENR 2016a). Only 3.2 per cent of the national total land is classified as protected forests (MENR 2016a). Records from Kenya Wildlife Service estimate that terrestrial protected areas (game parks and nature reserves) represent 8.05 per cent of the total land area. In addition, private conservancies exist whose spatial extent is not yet well consolidated. Therefore, the percentage of land that can be classified as biodiversity hotspots is around 15 per cent of the total land area. However, the figure could be slightly lower because of overlaps between natural forests and wildlife protected areas, as in the Mount Kenya ecosystem.

Since Kenya is classified as a low-forest-cover state, there are concerted efforts to expand the area of protected forest cover through gazettement of additional forests such as Boni forest in an effort to align the forest sector with Vision 2030 (GoK 2007) and the Constitution of Kenya 2010, which calls for increasing the forest and tree covers to 10 per cent respectively. According to the National Forest Program a forest is defined as an area of ≥0.5 hectares dedicated to forestry use and having a crown cover of ≥ 10 per cent and a tree height of ≥ 2.5 m. Once trees are planted, they facilitate a gradual increase in floral and faunal biodiversity. The National Forest Program provides a roadmap for increasing the forest cover for various land use types and provides a national baseline against which national intentions and targets can be periodically monitored. This can contribute to the GBEP indicators once they get internalized into national operations.

The recent Restoration Opportunity Assessment and Mapping exercise provides national and segregated county data on restoration opportunities across various land-use types (MENR 2016b). Following the exercise, Kenya has committed to rehabilitating 5.1 million hectares as its Nationally Determined Contribution to the Bonn Challenge of rehabilitating 150 million hectares by 2020 and 350 million hectares by 2030.

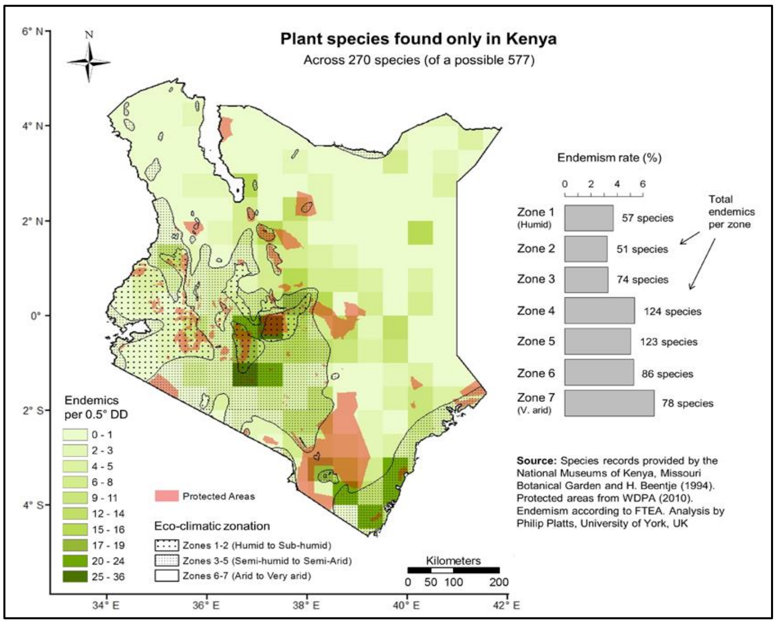
Kenya is a party to the Convention on Biological Diversity, and under Article 6 of the Convention it is expected to report regularly to the Conference of Parties on the progress made in the implementation of the Convention. To this end, Kenya has submitted four reports, in 1998, 1999, 2005 and 2009. The guidelines for the preparation of the national report are that it should contain four chapters, on: 1) biodiversity status, trends and threats, 2) the current status of the National Biodiversity Strategy and Action Plan, 3) sectoral and cross-sectoral integration of biodiversity considerations, and 4) progress towards biodiversity targets and implementation of the strategic plan. The national goals of Kenya's strategic action plan for biodiversity conservation, as stated in the first national report (1998), are:

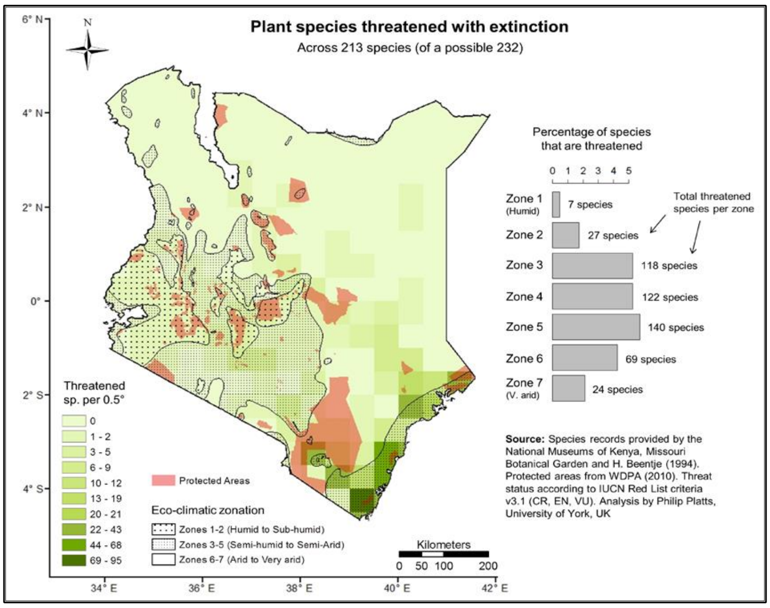
1) To ensure and maintain a high-quality environment that permits a life of dignity and well-being for all;
2) To achieve sustainable utilization of resource ecosystem for the benefit of the present generations, while ensuring their potential to meet the demands of future generations;
3) To maintain ecosystems and ecological processes essential for the functioning of the biosphere; and
4) To preserve genetic resources and biological diversity in the nation's ecosystems and to preserve their cultural value.

The aforementioned goals were adopted in the Constitution of Kenya 2010. Chapter 5 on Land and Environment part 2 is dedicated to Environment and Natural Resources. Subsequently, the relevant policies and acts of Parliament have been aligned with the Constitution to ensure sustainable biodiversity management, utilization and protection.

The foregoing attests to Kenya's national commitment to sustainable management and protection of biological diversity, and several efforts exist towards the commitment. The most comprehensive national effort on biological diversity in the landscape is reported in Kenya's Biodiversity Atlas (MEWNR 2015). The report provides national maps describing all plant species found in the country (Map 4.7a) and highlights endemic species (Map 4.7b). When used alongside the forest cover map, the atlas provides baseline data against which the biological indicator envisaged under GBEP will be assessed on the basis of periodic land-use changes.

Map 4.7. a. Diversity and distribution of plant species across Kenya. b. Distribution of endemic plant species across Kenya





Source: Cited in MEWNR 2015

BAGASSE BRIQUETTES

In Kenya commercial briquettes are produced from bagasse, which is industrial waste from sugar processing industries. Briquettes are increasingly being used in tea factories across Kenya, thereby substituting industrial oil and primary wood biomass. With regard to biodiversity, industrial use of briquettes in tea factories has positive impacts in that there will be gradual reduction in the consumption of primary wood biomass obtained from forests and woodlands, thereby contributing to forest and biodiversity conservation.

CHARCOAL

In Narok County, charcoal production is rampant in Narok South, with severe environment impacts. These impacts range from localized decimation of indigenous species such as *Acacia nilotica, Acacia xanthopholea*, *Euclea schimperi*, *Olea africana* and *Rhus natalensis* leading to the conversion of woodlands into open grasslands (Mweru 2018). The indiscriminate exploitation of trees is generally higher on private land than in protected government forests. Historical trends indicate the gradual loss of forest area, conversion of forests to bushlands and farm expansion, as exemplified by Loita Forest ecosystem (Mweru 2018). However, data meeting the criteria defined in the biological diversity indicator are missing except for outdated, scant information on Masai Mau forest cover change between 1986 and 2005.

For Kitui County, charcoal production is more intense in Kitui East, North and South, with varied impacts on the ecology and on woodlands hectarage (Kiruki et al. 2017; Ndegwa et al. 2016). These studies provide evidence of 24 per cent woodland loss between 1986 and 2014 in parts of Kitui South (Kiruki et al. 2017); but more work is required on cover change trends in all the charcoal-producing hotspots.

4.7.5 Conclusions and recommendations

Synthesis of the findings

Kenya is a biodiverse country with a large number of plant and animal species but also facing a large threat to species richness from natural and anthropogenic effects.

Forest land has been endangered for many years due to the extensive use of forest species. Charcoal production has impacted some tree species in some regions in Kenya such as Narok and Kitui counties.

Alternative uses of biomass (agriculture and forest residues) may contribute to reducing pressure on forests and biodiversity in these systems.

Practices and policies

Different policy instruments have been set up in Kenya to protect biodiversity and to improve the current degraded areas.

Kenya is a signatory of the Convention on Biological Diversity, and objectives are also reflected in national policies

Future monitoring

There is still a need to monitor individual farmlands and woodlands regarding the use of local tree species for charcoal production, which puts pressure on particular species and biodiversity at the local level.

4.7.6 References

Government of Kenya (2007). *Kenya Vision 2030.* Ministry of Planning and National Development and National Economic and Social Council (NESC), Office of the President. Nairobi.

Government of Kenya (2015). *Fifth National Report to the Conference of Parties to the Convention on Biological Diversity*. Nairobi. https://www.cbd.int/doc/world/ke/ke-nr-05-en.pdf.

Kiruki, H., van der Zanden, E., Malek, Z. and Verburg, P. (2017). Land cover change and woodland degradation in a charcoal producing semi-arid area in Kenya. *Land Degradation and Development* 28, 472-481.

Ministry of Environment, Water and Natural Resources (2015). *Kenya Biodiversity Atlas*. Nairobi.

Ministry of Environment and Natural Resources (2016a). National Forest Programme of Kenya. Nairobi.

Ministry of Environment and Natural Resources (2016b). *Technical Report on the National Assessment of Forest and Landscape Restoration Opportunities in Kenya*. Nairobi.

Mweru, P.K. (2018). *Use and Conservation of Wild Medicinal and Food Plants in Loita, Narok County, Kenya.* PhD Thesis submitted in Partial Fulfilment for Degree of Doctor of Philosophy in Dryland Resource Management. University of Nairobi.

Ndegwa, G.M., Nehren, U., Grüninger, F., Iiyama, M., et al. (2016). Charcoal production through selective logging leads to degradation of dry woodlands: a case study from Mutomo District, Kenya. *Journal Arid Land* 8, 618-631.

4.8 Indicator 8. Land use and land-use change related to bioenergy feedstock production

4.8.1 Definition

(8.1) Total area of land for bioenergy feedstock production, and as compared to total national surface and (8.2) agricultural land and managed forest area;
(8.3) Percentages of bioenergy from: (8.3a) yield increases, (8.3b) residues, (8.3c) wastes, (8.3d) degraded or contaminated land;
(8.4) Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production, including the following (among others):

- arable land and permanent crops, permanent meadows and pastures, and managed forests
- natural forests and grasslands (including savannah, excluding natural permanent meadows and pastures), peatlands and wetlands.

4.8.2 Measurement unit(s)

(8.1-2) hectares and percentages (8.3) percentages (8.4) hectares per year

4.8.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

The pathway relates to bioenergy feedstock that does not have a direct negative impact on land use change, since agricultural waste is being used as the feedstock. There is no net annual rate of land conversion caused by the feedstock production; however, there is attributable public or private forest conservation. The analysis hence avoided standing biomass stock that would have otherwise been harvested in the absence of the project activity.

The indicator considers land use for bioenergy feedstock at the national level, based on data estimates from reports. As the share of bagasse increases, the per cent share of wood reduces. The assumption was made that the use of biomass briquettes would increase nationally to a 30 per cent share in the tea industries. Because agricultural waste is the feedstock, the methodology considered a percentage of bioenergy from crop residue.

CHARCOAL

The indicator is defined as the total area of land for bioenergy feedstock production, as compared to the total national surface area and (8.2) agricultural land and managed forest area (FAO 2011).

This indicator will make it possible to put in perspective the land use for bioenergy feedstock (tree on farm) production at the national level. National statistical records were used to highlight the national total figures for land use and land-use changes. The indicator is based on point estimates. The total land area for bioenergy feedstock was calculated and prorated based on focused national charcoal demand, yield of biomass and estimated harvesting period. According to the farm forestry rule, sustainable harvesting should ensure 10 per cent tree cover on agricultural land (GoK 2009). As such, total farm forestry should be calculated above 10 per cent of total national farmland. The study did not consider land suitability assessment due to the lack of information. Key data used in the calculation are shown in Table 4.11.

Table 4.11. Data on land use and land cover in Kenya

National land cover	58.04 million ha
Total charcoal demand	1 370 000 tons
Charcoal conversion	12% efficiency
Firewood required for charcoal production	11 416 666.67 tons
Volume of wood for charcoal	16 325 833.33 m^3
Natural grown trees on farm	6 237 419.00 m^3
Wood yield	17.50 m^3/ha
Crop land (farm land)	6.46 million ha
Pasture land (range land)	21.72 million ha
Regulation 10% tree on-farm	0.65 million ha

4.8.4 Key findings

BAGASSE BRIQUETTES

The indicator is defined in sub-indicator 8.3 as the percentages of bioenergy from residues. This is because the indicator's scope does not encompass net annual rates of conversion between land-use types caused directly by bioenergy feedstock production as a fraction of total land area, agricultural land and managed forest area in sub-indicators 8.1 and 8.2 (FAO 2011).

From FAO statistics, total national land cover is 58.04 million ha, with agricultural land accounting for 49 per cent of this and forest accounting for 7.75 per cent. The statistics show a 2 per cent growth in agricultural land and a 0.64 per cent increase in forest cover between 2005 and 2015. The land use and land cover definitions in Kenya, as classified by FAO, are summarized in Table 4.12.

Table 4.12. FAO classification of land use and land cover types in Kenya

Kenya total land cover and land use (58.04 million ha)		Per cent	
Forest land		*7.75%*	*Share of land area*
	Primary forest	0%	Share of forest land
	Planted forest	4.99%	Share of forest land
	Other naturally regenerated forest	95.01%	Share of forest land
Agricultural land		*48.55*	*Share of land area*
	Land under permanent meadows and pastures	77.09%	Share of agricultural land
	Cropland	22.91%	Share of agricultural land
	Arable land	20.99%	Share of agricultural land
	Land under permanent crops	1.92%	Share of agricultural land
	Agriculture area under organic agriculture	0.54%	Share of agricultural land
Crop land		*11.12%*	*Share of land area*
Land under permanent meadow and pasture land		*37.42%*	*Share of land area*

Source: FAOSTAT n.d.

The tea sector is a high consumer of firewood (around 1.9 kilograms per kilogram of tea) (Salva and ForTeA 2015). Using a conversion factor of 1.43 m^3/ton for firewood, for 800,000 tons of firewood demanded in 2015, national demand in the tea industry was around 1.14 million m^3 of wood. Replacing 30 per cent of the firewood used in the tea industries would reduce 342,000 m^3 of wood nationally per year required for tea processing. According to the Kenya Forestry Service, a public plantation would yield 407.4 m^3 per hectare at full maturity (30 years). Translating 342,000 m^3 of wood to land area results in around 840 hectares that would be conserved annually. Cumulatively this could potentially yield 25,000 hectares of forest plantation in 30 years, or around a 1 per cent increase in forest cover.

CHARCOAL

The FAO classifies land use and land cover broadly as forest lands, agricultural land, crop land and land under permanent meadow and pasture land. This is further sub-categorized as primary forest, planted forest and naturally regenerating forest, which accounts for the bigger percentage of forest land (95 per cent); agricultural land includes land under permanent meadow, crop land, arable land, land under permanent crop and agricultural area under organic agriculture (FAOSTAT n.d.). In contrast, the Kenya Forest Service description of national forest land is summarized in Table 4.13.

Table 4.13. Forest coverage in Kenya by type, 2012-2015

	2012	2013	2014	2015
Forest cover type	**Thousand hectares**			
Indigenous closed canopy	1 137	1 137	1 139	1 140
Mangroves	54	54	54	54
Public plantation forest	127	135	130	132
Private plantation forest	94	71	80	82
Sub-total closed canopy forest	1 412	1 397	1 403	1 408
Open woodland	2 052	2 053	2 056	2 056
Sub-total of forest areas	3 464	3 450	3 459	3 464
Bushland	24 245	24 245	24 260	24 255
Grassland	10 528	10 664	10 670	10 665
Trees on farmland	10 411	12 400	12 450	12 520

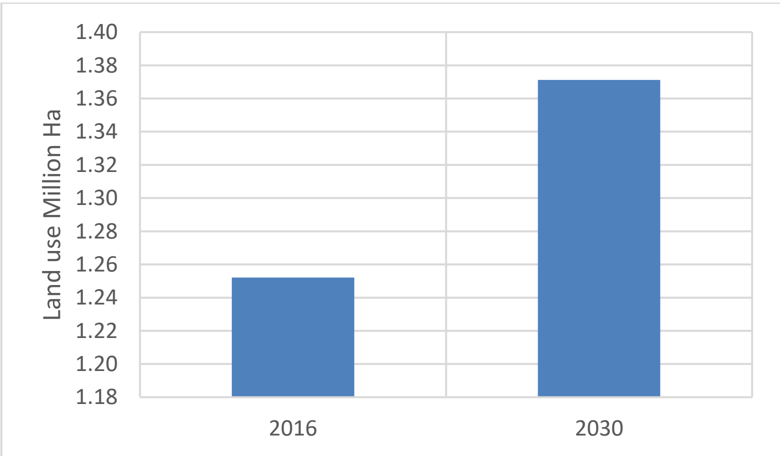
Source: KNBS 2018

The agriculture (farm forestry) rule requires all agricultural land to maintain a farm forestry cover of at least 10 per cent (GoK 2009). Farm forestry is defined as the practice of managing trees on-farm, whether singly or in lines, rows, boundaries, woodlots and private forest. Farm forestry as defined in the regulation includes both rangeland and cropland. Agricultural land constitutes 49 per cent of total land cover equating to 28.4 million hectares, whereas forest land covers only 7.5 per cent (FAOSTAT n.d.).

In this pathway, trees on farm and in the rangeland constitute the bioenergy feedstock. As described in the GBEP handbook, increasing bioenergy production could require either intensification of agriculture (i.e., increased land use) or changes in cropping patterns. However, as defined in farm forestry above, the bioenergy would result in changing the cropping pattern and enhancement of farm forestry.

The total land required for bioenergy while maintaining 10 per cent agroforestry is 1.25 million hectares. This is a sum of the 10 per cent trees on-farm (0.65 million ha), land for sustainable charcoal production (0.96 million hectares) less naturally growing trees in the range land (0.356 million hectares) in 2016. A study by the Ministry of Environment Water and Natural Resources (2013) shows that naturally grown trees – constituting trees in pasture and range land – is around 6.2 million m^3 occupying an area of 0.36 million ha. Sustainable bioenergy, as defined, is wood sourced sustainably from farmland and range land. Thus, net additional land required for bioenergy is 0.61 million hectares of land in farmland. The percentage of land for bioenergy as a share of agricultural land (cropland and pastureland) and total national land cover was thus determined to be 4 per cent and 2 per cent respectively (Figure 4.13).

Figure 4.13. Land use change for charcoal production



4.8.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

As the pathway considers the use of sugarcane bagasse briquettes as alternative energy there is no annual rate of land conversion caused by bioenergy feedstock production, and thus net forest conservation. The factory uses 2 m^3 of wood per hour which translates to around 22,426 m^3 of wet wood annually, and 30 per cent replacement would yield 6,727.7 m^3 of wood land cover conservation estimated at 17 hectares of land annually. Moreover, based on recent findings from the tea factory visit, 1 m^3 of wood is equivalent to 550 kilograms, and thus total national wood demand would be 627 tons annually, translating to 188 tons of wood avoided on a dry basis.

Practices and policies to improve sustainability

Biomass briquettes present an opportunity for forest conservation and should be promoted as such. Sugarcane bagasse is currently underutilized, not even as compost, and hence has no inhibiting competitive use.

Future monitoring

Only 4 per cent of this resource has been adopted in the tea industries; however, there is a deliberate campaign by the sector to increase the fuel-to-briquette mix to 30 per cent. This calls for further analysis on the technical, economic and downstream feedstock availability. Besides most sugarcane factories in Kenya are in a downward growth trend, coupled with regional trade in sugar, it will be worth monitoring the sustainable supply of the resource in the near- and long-term futures.

CHARCOAL

Synthesis of the findings

The demand for charcoal continues to be a challenge in Kenya. Therefore, considerations for future alternative feedstock for bioenergy such as agricultural residues need to be prioritized.

Practices and policies to improve sustainability

If the bioenergy is to be grown on cropland, radical shifts in farm management practices need to be devised. Assuming that both the regulation calling for 10 per cent trees on-farm and the production of trees for bioenergy are implemented on crop land, then the total crop land under farm forestry would be 24 per cent, constraining agricultural productivity. This might lead to the need for trade-off and synergy analysis on the bioenergy pathway.

Charcoal production from farmland and rangeland shall be done mainly on rangeland. Reclamation of rangeland and mixed fodder and tree planting present an opportunity for wood for energy while preserving national forest cover.

Suitable tree species that could be intercropped need to be researched on and promoted. Whether bioenergy is intercropped with food crops or in woodlots, it will have a significant impact on soil quality.

Future monitoring

Data on forest area and yields need to be organised and updated at least every five years to be able to compare the forest land used for charcoal production and fuelwood.

4.8.6 References

Food and Agriculture Organization of the United Nations (2011). *The Global Bioenergy Partnership Sustainability Indicators for Bioenergy*. Rome.

FAOSTAT (n.d.). Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/EL. Accessed 23 May 2019.

Government of Kenya (2009). *The Agriculture (Farm Forestry) Rules, 2009. Pub. L. No. Agriculture Act (Cap 318).* Nairobi.

Kenya National Bureau of Statistics (2018). *Economic Survey, 2017.* Nairobi. https://www.knbs.or.ke/download/economic-survey-2017/.

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of the Charcoal Value Chain in Kenya.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Ministry of Environment, Water and Natural Resources (2013b). *Analysis of Demand and Supply of Wood Products in Kenya Study.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%2Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Salva, T. and ForTeA (2015). *Opportunities for Improving Efficiency in Forestry Operations and Forest Products Processing in Kenya.*

4.9 Indicator 9. Allocation and tenure of land for bioenergy production

4.9.1 Definition

Percentage of land – total and by land-use type – used for new bioenergy production where: (9.1) a legal instrument or domestic authority establishes title and procedures for change of title; and (9.2) the current domestic legal system and/or socially accepted practices provide due process and the established procedures are followed for determining legal title.

4.9.2 Measurement unit(s)

Percentage

4.9.3 Overall methodology of the implementation

- Literature review (journals, non-governmental organization reports, government reports.
- Links to environmental Indicator 8 on land use.

4.9.4 Key findings

Land tenure refers to the terms and conditions under which rights to land and land-based resources are acquired, retained, used, disposed of or transmitted. Existing policies and laws on land have protected private land rights, especially under the Registered Land Act, at the expense of indigenous or communal land rights. Land tenure is the act, right or period of holding land.

Legal land tenure in Kenya

Land tenure in Kenya falls under four different entities: government (public), county councils (local authorities), individuals (private) and groups (communal). Different legal instruments govern different categories of land and its owners. To date, land ownership in over 40 per cent of Kenya remains informal.

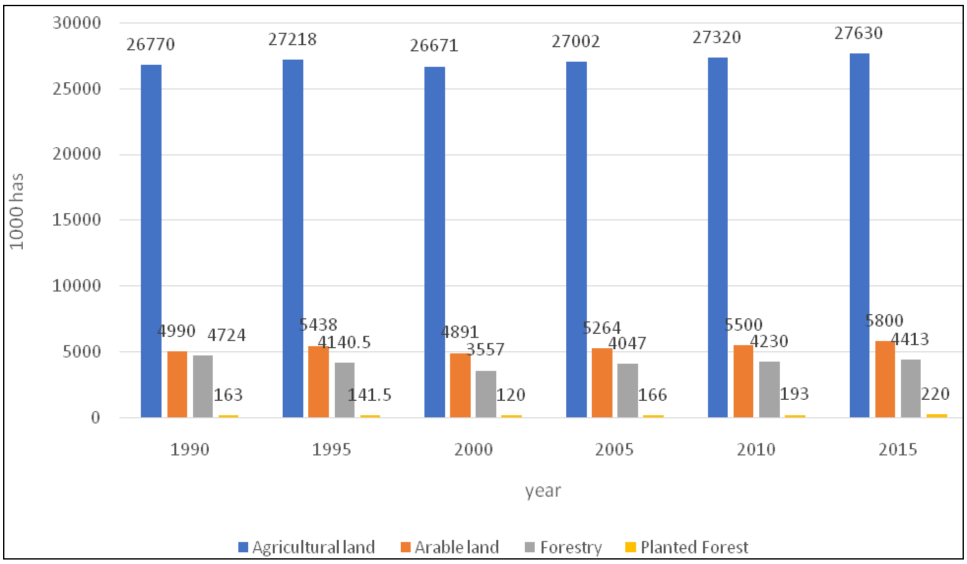
According to the Constitution of Kenya (2010), land is classified as public, community or private, but in principle it belongs to the people of Kenya collectively. Community tenure dominates most rural lands in Kenya, while the private and public tenure systems control land in urban areas. The Constitution also states that the land should be managed in a “suitable, efficient, productive and sustainable” form. The second most important legal instrument is the National Land Policy, which focuses on how land tenure resources are acquired, retained, used, disposed of, or transmitted (Kameri-Mbote 2016).

Regarding the institutions that govern land, the National Land Commission’s main function is to manage public land on behalf of the national and county governments (KLRC 2019). Public land in Kenya includes forest reserves, water bodies, national parks, townships and other urban centres,

land reserved for government institutions and any other special category of land that may be acquired by the government for public use. Estimates indicate that 10 per cent of land in Kenya is currently categorized as public tenure (Kameri-Mbote 2016).

One of the broad range reforms introduced in the 2010 Constitution was the formation of a National Land Commission to act as the lead agency in land matters, working with the Ministry of Lands, Housing and Urban Development and county-level institutions (NLC 2019a). The National Land Commission derives its mandate from several legal instruments: the Constitution of Kenya (2010), the National Land Policy of 2009, the National Land Commission Act of 2012, the Land Act 2012, the Land Registration Act of 2012 and the Land (Amendment) Act of 2016 and other enabling statues (Yetu et al. 2019).

Figure 4.14. Land use in Kenya by category, 1990-2015



Source: FAOSTAT 2019

Free hold and lease hold

There are two types of land tenure system in Kenya: free hold and lease hold.

1) *Freehold* is the greatest interest that a person can have in land as it gives the holder absolute ownership of the land for life. This means that descendants can succeed the owner for as long as the family lineage exists. A freehold title deed generally has no restrictions as to the use or occupation. However, there are conditional freeholds, which restrict the use of the land, for instance, for agricultural purposes or ranching only. A freehold interest is also known as fee sample or absolute proprietorship.

2) *Leasehold* is the interest in land for a specific period subject to payment of a fee or rent to the grantor. Payment of rates is made to the respective county governments for services rendered such as roads, water, security among others. Leases are granted by the government for public land, local authority for trust land and individuals with freeholds. The maximum term of government leases is 99 years (NLC 2019b).

Some issues

The individualization of land rights has, however, undermined indigenous culture and conservation systems, especially in areas inhabited by pastoral communities. In addition, colonial and post-colonial land administration in pastoral areas destroyed traditional resource management

institutions, thereby creating uncertainty in access, exploitation and control of land and land-based resources (NLC 2019a).

A comprehensive study by Kameri-Mbote (2016) identified 16 key issues regarding different aspects of land tenure in Kenya. Among them is the lack of data on land converted from private use to public use through compulsory acquisition. This lack of data hinders proper review of the processes followed in land acquisition. Kameri-Mbote (2016) indicated that the National Land Commission was preparing criteria and guidelines for land acquisition for public purposes.

Another key issue identified was land governance, which was not clear, and therefore the author suggested an assessment "to re-organize, update, authenticate and digitize land information for ease of access and facilitation of the recognition and protection of rights". In addition, it was indicated that cadastral maps and registry records are necessary and need to be updated.

Gender and land tenure

In Kenya, a woman's right to own property, inherit and manage or dispose of her property has long been under attack from customary practices that grant women only secondary rights to land and property through male relatives. Data gathered by the Federation of Women Lawyers (FIDA) shows that while about 32 per cent of households in Kenya are headed by women, they hold only 1 per cent of land titles on their own, while 5 per cent own land jointly with male relatives (Mbugua 2018).

In 2013 the country made some moves to strengthen women's land rights by passing the Matrimonial Property Act 2013, which reinforced the equal rights enshrined in the constitution for both spouses when they own property together and granted some new rights to women landowners. But law experts and rights advocates say there are still too many obstacles – including cultural tradition and lack of awareness – that stop many women from accessing their fair share of land and property, especially in cases of inheritance (Mbugua 2018).

4.9.5 Conclusions and recommendations

Synthesis of the findings

Overall the land tenure system in Kenya is clear and establishes the different types of property. Nevertheless, the enforcement system on land property continues to be a problem. The link to the property for the production of different types of biomass used for bioenergy will need to be assessed with different sources and material that was not ready at the time of writing this report.

Practices and policies to improve sustainability

The legal system for land tenure still has gaps to address in the national policy.

Gender issues on land rights are more common in rural areas.

Future monitoring

Publicly available data are needed on the proportion of land under the different types of tenure.

4.9.6 References

FAOSTAT (2019). Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#home. Accessed May 2019.

Kameri-Mbote, P. (2016). *Kenya Land Governance Assessment Report*. World Bank. Washington, D.C. p. 129. http://documents.worldbank.org/curated/en/829991504864783043/pdf/119619-WP-P095390-PUBLIC-7-9-2017-10-9-20-KenyaFinalReport.pdf.

Kenya Law Reform Commission (2019). *Constitution of Kenya*. http://www.klrc.go.ke/index.php/constitution-of-kenya/117-chapter-five-land-and-environment/part-1-land/234-67-national-land-commission.

Ministry of Lands (2007). *National Land Policy*. http://theredddesk.org/sites/default/files/ministry_of_lands_2007_national_land_policy.pdf. Accessed May 2019.

Mbugua, S. (2018). Despite new laws, women in Kenya still fight for land rights. https://www.newsdeeply.com/womensadvancement/articles/2018/02/23/despite-new-laws-women-in-kenya-still-fight-for-land-rights.

National Land Commission (2019a). FAQ on land. https://www.landcommission.go.ke/article/faqs. Accessed May 2019.

National Land Commission (2019b). *First Commissioners 2013-2019. End Term Report*. http://www.landcommission.go.ke/media/erp/upload/first_commissioners_end_term_report.pdf.

Yetu, A., Yetu, M. and Wetu, U. (2019). *National Land Commission 2013–2019 First Commissioners End Term Report. First Commissioners End Term Report 2013-2019*. National Land Commission. Nairobi. P. 138.

4.10 Indicator 10. Price and supply of a national food basket

4.10.1 Definition

(10.1) Effects of bioenergy use and domestic production on the price and supply of a food basket, which is a nationally defined collection of representative foodstuffs, including main staple crops, measured at the national, regional, and/or household level, taking into consideration:

- Changes in demand for foodstuffs, feed and fibre
- Changes in the import and export of foodstuffs
- Change in agricultural production due to weather conditions
- Changes in agricultural costs from petroleum and other energy prices
- The impact of price volatility and price inflation of foodstuffs on the national, regional, and/or household welfare level, as nationally determined.

4.10.2 Measurement unit(s)

Tons; US dollars; national currency (Kenyan shillings); percentage

4.10.3 Overall methodology of the implementation

A literature review and assessment were done, based on the Kenya National Bureau of Statistics horizontal analysis (2005-2015) on poverty and food and non-food expenditure using the national food basket.

A family food basket is based on the prevalent food situation of a country and on the money value of it based on minimum wages. It considers the quantity of food that should be included in the diet (Flores and Bent 1980).

Kenya National Bureau of Statistics (2018a) assessed welfare based on consumption expenditures and computed the poverty line of Kenya including the food basket as follows: "*In practice, computing the poverty line involves several steps starting with determining a calorie requirement, creating a food basket, and evaluating the cost of meeting the calorie requirement using that food*

basket. The cost of this basket is the food poverty line which is used to determine the proportion of the population that is unable to meet the minimum basic food consumption needs (i.e. the food poor). A minimum allowance for non-food consumption is then added to the food poverty line to determine the overall poverty line which is used to determine the proportion of the population that is unable to meet the minimum overall basic consumption needs (i.e. the absolute poor). All estimates for the poverty line are based on median national reference prices and monthly per-adult-equivalent expenditures to adjust for differing needs across households of differing sizes and composition. In accordance with past practice, separated poverty lines were computed for the rural and urban population in Kenya." (KNBS 2018a, p. 25).

4.10.4 Key findings

The well-being report used different indicators for the computation. For the GBEP indicator only two disaggregated indicators were used related to bioenergy:

- Food, beverages and related items over the last seven days.
- Expenditures on house rents, water, electricity, gas and other cooking fuels (charcoal) over the last one month. The focus was on electricity, gas and cooking fuels (charcoal).

Following international standards to re-evaluate the food poverty line at intervals of 10 or more years and to update the baskets for changes in lifestyle and taste, Kenya National Bureau of Statistics (2018a) compared the 2015/16 and 2005/06 rural and urban food poverty line baskets, demonstrating changes in food consumption tastes (Table 4.14).

Table 4.14. Summary of 2015/16 headcount poverty measures in Kenya

Residence	Headcount poverty measures	Poor persons (% of population)	Poor persons (thousands)	Poor households (% of households)	Poor households (thousands)
National	Food poverty	32.0	14 539	23.8	2 718
	Overall poverty	36.1	16 401	27.4	3 126
Rural	Food poverty	35.8	10 419	28.1	1 808
	Overall poverty	40.1	11 687	32.6	2 097
Peri-urban	Food poverty	28.9	965	21.5	173
	Overall poverty	27.5	920	21.1	166
Core-urban	Food poverty	24.4	3 155	17.7	736
	Overall poverty	29.4	3 795	20.6	880

Source: KBSN 2018a

The trends in poverty incidence between 2005/2006 and 2015/2016 were analysed, but only three out of six indicators are presented in this report (KNBS 2018a) as per Table 4.15. It can be observed that overall there was poverty reduction, particularly in rural areas, as well as a reduction in food poverty, particularly in peri-urban areas.

Table 4.15. Poverty trends in Kenya, 2005/2006 and 2015/2016

Indicator	Place of residence	Poor persons 2005/2006	Poor persons 2005/2006*	Poor persons 2015/2016	10-year change
Overall poverty rate (%)	National	46.6	46.8	36.1 -	-10.7
	Rural	49.7	52.5	40.1	-12.4
	Peri-urban	N/A	42.5	27.5	-15
	Core-urban	34.4	32.1	29.4	-2.7
Food poverty rate (%)	National	45.8	44.4	32.0	-12.4
	Rural	47.2	49.5	35.8	-13.7
	Peri-urban	n/a	43.3	28.9	-14.4
	Core-urban	40.4	29.0	24.4	-4.6
Population living in overall poverty (millions)	National	16.6	16.6	16.4	-0.2
	Rural	14.1	12.0	11.7	-4.8
	Peri-urban	n/a	2.3	0.9	0.1
	Core-urban	2.5	2.3	3.8	2.8

* Comparable 2005/06 poverty line (revaluing the 2015/16 basic basket using 2005/06 prices); N/A = not available

Source: KNBS 2018a

The report of Kenya National Bureau of Statistics (2018a) compared the food baskets in rural and urban areas. It analysed the main products included in the food basket, their prevalence in urban and rural areas, the edible kilocalories per 100 grams of each food item, the median prices and the correspondent expenditures in poor households (KNBS 2018a).

From this analysis they concluded that “at prevailing median prices and consumer tastes in rural Kenya (as reflected by the average expenditure shares), the total cost of purchasing the minimum daily adult equivalent calorie requirement amounts to KSh 64.23. Therefore, rural food poverty line in monthly adult equivalent terms was determined to be KSh 1,953.50” (KNBS 2018a, p. 27). For urban areas, the calculation indicated that “at prevailing median prices and consumer tastes in urban Kenya (as reflected by the average expenditure shares), the total cost of purchasing the minimum daily adult equivalent calorie requirement amounts to KSh 83.86. Thus, the urban food poverty line in monthly adult equivalent terms was determined to be KSh 2,550.80” (KNBS 2018a, p. 28). This shows that food poverty is higher in urban areas than in rural areas.

For both pathways selected in the GBEP analysis for Kenya, Tables 4.16 and 4.17 show 10 selected food items from the food basket reported by Kenya National Bureau of Statistics (2018a) for urban and rural areas. The selected items are the most important as indicated in the report, and tea leaves were added considering the pathway 1 area of influence, although tea leaves were not ranked in the top 10 most important items in the basket.

Table 4.16. Urban food basket in Kenya

Food item	Share in basket	Kcal (100 g)	Median urban price (KSh / 100 g)	Kcal per KSh 100	KSh for 2 250 Kcal
Unpacked fresh cow's milk	0.080	72	6.0	95.7	6.68
Sugar	0.072	375	10.0	268.5	6.00
Loose maize flour	0.064	264	5.0	336.5	5.34
Beef with bones	0.053	223	40.0	29.8	4.48
Cooking oil	0.052	900	15.8	293.1	4.32
Non-aromatic white rice	0.049	346	9.0	189.9	4.14
White bread	0.041	261	12.5	86.6	3.48
Beans	0.041	324	8.0	167.6	3.47
Tomatoes	0.038	27	8.0	12.9	3.20
Mutton / Goat meat	0.032	253	40.0	20.1	2.67
Tea leaves	0.016	40	50.0	1.3	1.34

Source: KSBN 2018a

Table 4.17. Rural food basket in Kenya

Food item	Share in basket	Kcal (100 g)	Median urban Price (KSh / 100 g)	Kcal per KSh 100	KSh for 2 250 Kcal
Loose maize flour	0.164	264	5.0	863.5	10.50
Unpacked fresh cow's milk	0.105	72	5.0	150.5	6.71
Sugar	0.090	375	10.3	329.4	5.81
Beans	0.064	324	8.0	257.6	4.09
Loose maize grain	0.038	353	3.5	385.4	2.45
Non-aromatic white rice	0.029	346	8.0	126.9	1.88
Cooking oil	0.028	900	16.5	152.3	1.79
Traditional vegetables	0.027	42	5.0	22.5	1.72
Potatoes	0.025	81	4.0	51.6	1.64
Kale (sukuma wiki)	0.024	52	4.0	30.5	1.52
Tea leaves	0.017	40	50.0	1.4	1.09

Source: KSBN 2018a

The main difference between the two food baskets (rural and urban) is in the consumption of meat, which is more significant in urban areas. Nevertheless, the link between the food basket and the energy consumption (in terms of prices) required to analyse the prices of energy used at the household level can be seen in Table 4.18.

Table 4.18. Supply and demand for non-renewable feedstocks, 2017

Energy Products	Wood charcoal	Fuelwood in logs, in billets, in twigs, in faggots or in similar forms	Wastes or scraps	Subtotal
	(terajoules)			
Domestic production	62 286.33	847 588.49	25 201.07	935 075.89
Total Supply	*62 286.33*	*847 588.49*	*25 201.07*	*935 075.89*
Statistical differences	0.00	1 146.64	0.00	1 146.64
Total Demand	*62 286.33*	*846 441.85*	*25 201.07*	*933 929.25*
Manufacturing	0.00	122 550.00	0.00	122 550.00
Households	62 286.33	723 891.85	25 201.07	811 379.25

Note: 1 terajoule = 10^12 joules
Source: KNBS 2018b

The supply of charcoal and firewood in the agricultural sector was estimated at 62,286.33 terajoules (TJ) and 846,441.85 TJ respectively (KNBS 2018b). As natural inputs for energy in 2017, biomass wood was reported as 122,550.00 TJ in the manufacturing sector and 787,342.82 TJ for households.

Table 4.19. Consumption of energy products in Kenya, 2017

Product	Household use	Manufacturing
	(terajoules)	
Firewood	723 891.85	122 550.00
Charcoal	62 286.33	
Wood/process waste	1 146.64	

Considering the amount of biomass demand and use at household level and the poverty levels, the prices of charcoal affect the affordability. Table 4.20 shows the variation of prices since 2015. The consumer price index is included to compare the affordability.

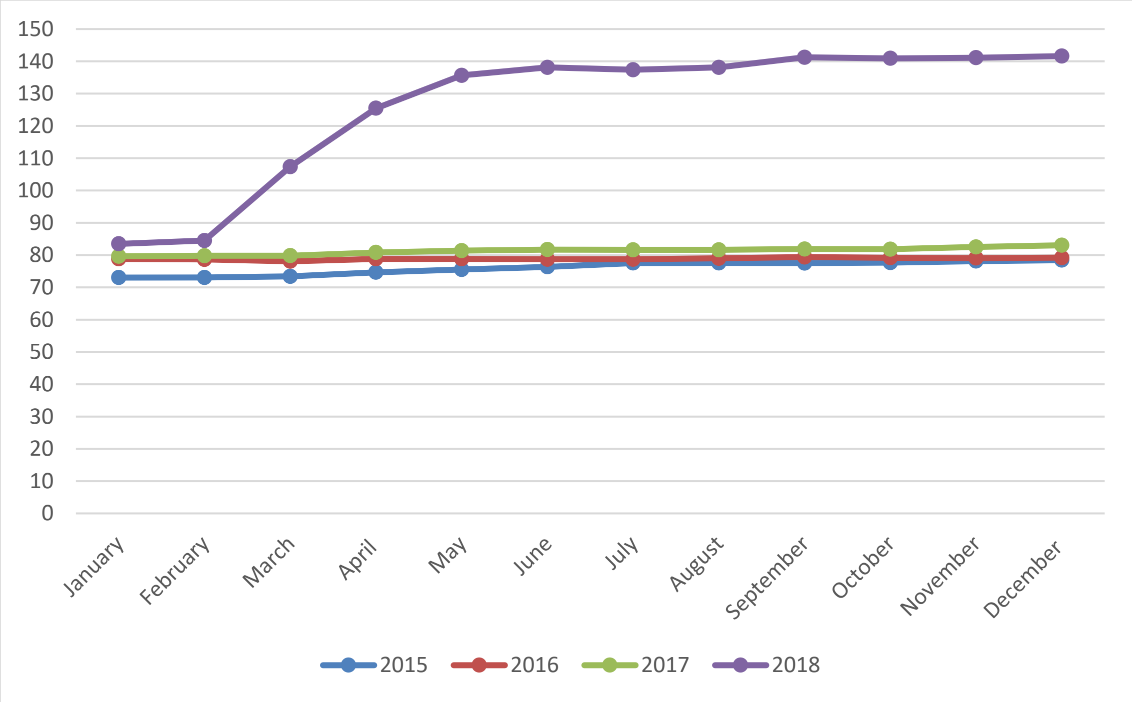
Table 4.20. Charcoal price per 4-kilogram tin in Kenya, 2015-2018

Month	Average price (KSh)	Consumer Price Index (CPI)	Average price (KSh)	Consumer Price Index (CPI)	Average price (KSh)	Consumer Price Index (CPI)	Average price (KSh)	Consumer Price Index (CPI)
	2015	2015	2016	2016	2017	2017	2018	2018
December	78.42	164.72	79.2	175.18	83.04	193.51	141.62	193.51
November	78.13	162.97	79.07	173.85	82.51	183.05	141.12	192.25
October	77.65	162.13	79.17	172.62	81.82	182.5	140.93	192.59
September	77.5	161.33	79.39	171.56	81.86	183.66	141.24	194.14
August	77.56	160.9	79	170.97	81.61	184.72	138.13	192.18
July	77.53	160.57	78.71	170.84	81.61	183.6	137.39	191.59
June	76.35	160.46	78.71	169.76	81.7	185.39	138.13	193.31
May	75.54	159.98	78.82	167.99	81.37	187.64	135.64	195.05
April	74.66	158.7	78.82	167.07	80.8	186.24	125.48	193.18
March	73.39	155.86	78.07	165.92	79.81	182.98	107.36	190.62
February	73.06	154.14	78.64	165.06	79.78	179.98	84.49	188
January	73.03	153.43	78.82	165.37	79.64	176.93	83.47	185.47

Source: KNBS, Economic Surveys 2015-2018

The price variation was higher in 2018 after the ban on logging in government-gazetted forests (Figure 4.15). It is assumed that the prices are higher because charcoal is being imported from Uganda to satisfy the internal demand and therefore this has an impact on the three issues analysed in this indicator: The food basket price, the urban and rural poor and the prices of charcoal for cooking.

Figure 4.15. Charcoal price (KSh) per 4-kilogram tin in Kenya, 2015-2018



Source: KNBS Economic Surveys 2015-2018

4.10.5 Conclusions and recommendations

The food poverty rate in Kenya has declined by 12 points of percentage in 10 years at the national level, by 14 points of percentage in rural and peri-urban areas and by 5 points of percentage in core urban areas.

Overall, the share of the population living in poverty has not changed at the national level, but it has declined by 4.8 points of percentage in rural areas, 0.1 points of percentage in peri-urban areas and 2.8 points of percentage in core urban areas.

The rural food poverty line in monthly adult equivalent terms was determined to be KSh 1,953.50 (KNBS 2018a, p. 27).

The urban food poverty line in monthly adult equivalent terms was determined to be KSh 2,550.80 (KNBS 2018a, p. 28).

The price of a 4-kilogram tin of charcoal increased from an average of KSh 76.06 in 2016 to around KSh 140 in 2018. The price of charcoal, which is used mainly for cooking, has increased since 2018 with the government ban on logging in gazetted forests in Kenya.

The overall reduction of poverty in Kenya is still relatively small. The main difference in the food basket between rural and urban areas is the affordability of meat.

Practices and policies to improve sustainability

Achieving sustainable charcoal production and other sources of energy with affordable prices should be part of an energy policy linking the Sustainable Development Goals.

Future monitoring

It is recommended to update the food basket indicator at the Kenya National Bureau of Statistics and review it every five years instead of every ten years. In addition, the information should be linked with the prices of fuels (charcoal, kerosene) and electricity.

4.10.6 References

Flores, M. and Bent, V.W. (1980). Family food basket. Definition and methodology. NCBI. NHI. https://www.ncbi.nlm.nih.gov/pubmed/7447589. Accessed March 2019.

Kenya National Bureau of Statistics (2018a). *Basic Report on Well-being in Kenya. Based on the 2015/16 Kenya Integrated Household Budget Survey (KIHBS)*. Nairobi. pp 96

Kenya National Bureau of Statistics (2018b). *Economic Survey 2018*. Nairobi. pp 340.

4.11 Indicator 11. Change in income

4.11.1 Definition

Contribution of the following to change in income due to bioenergy production:

(11.1) Wages paid for employment in the bioenergy sector in relation to comparable sectors.
(11.2) Net income from the sale, barter and/or own-consumption of bioenergy products, including feedstock, by self-employed households/individuals.

4.11.2 Measurement unit(s)

(11.1) local currency units per household/individual per year, and percentages (for share or change in total income and comparison)
(11.2) local currency units per household/individual per year, and percentages (for share or change in total income and comparison)

4.11.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

For bagasse briquettes, since most workers within the industry sector in Kenya work six days per week, it was assumed that a month has 24 working days. Therefore, daily wages were converted to monthly wages by multiplying the daily wages by 24. Literature review and interviews were conducted with selected briquette companies and tea factories

CHARCOAL

For charcoal, the majority of the actors involved in the charcoal value chain, not least the wood and charcoal producers, work on a daily basis, alternating their engagement in charcoal production with other activities, like farming. The charcoal market price used in this indicator is the average price for 2016, which corresponds to KSh 1,500 per bag (Onekon and Kipchirchir 2016). Based on the revenue share values presented by the Ministry of Environment, Water and Natural Resources (MEWNR 2013), the revenue for the different actors in charcoal production, distribution and commercialization were calculated.

Due to the lack of detailed data on production costs for the different actors along the charcoal value chain, the net income per activity and individual could not be calculated. Thus, only revenue values are presented for the charcoal pathway. Revenue values for each actor along the charcoal value

chain are presented per amount of charcoal produced rather than on an individual basis. This is due to the lack of accurate information on the number of individuals involved in each activity in the value chain.

4.11.4 Key findings

BAGASSE BRIQUETTES

Activities in this indicator are from the acquisition of the bagasse and from the following income-generating activities indicated in the description of the sugarcane bagasse briquettes. The wages and specifics of each of these activities are based on the information gathered during the interviews.

Bagasse transport from the sugar factory to the briquetting plant

One of the interviewed bagasse briquetting plants was located within the sugar factory, and thus no transport was required. The transport distance (considering a two-way trip, since the vehicle travels empty on its way back to the sugar factory) was 58 kilometres on average. In most cases, a driver and an assistant are involved in the transport.

The interviewed bagasse processing plants did not have information on the wages for transport workers, as transport is typically included in the price of the bagasse. According to the Economic Survey 2018 (KNBS 2018), the average annual wage earning per employee within the transport and storage sector in Kenya in 2016 was KSh 1,203,430 ($11,905) (Table 4.21).

Bagasse drying

In most bagasse briquetting plants, bagasse is usually dried in the sun. Women often carry out the task of sun drying the bagasse. These are entirely informal jobs. According to the information gathered during the interviews, a woman can dry around 300 kilograms per day (final dry weight) on a sunny day. They are paid KSh 1.5 per kilogram of dry bagasse, or KSh 450/day ($4.45 per day) in the best cases.

In one of the interviewed companies, bagasse was dried in a rotary drum drier. The monthly wage for the bagasse drier operator was KSh 10,800 ($106.8), corresponding to KSh 129,600 per year.

Briquette processing

The dry bagasse is fed into the briquetting presses either manually or automatically by means of a conveyor belt. The bagasse is converted to briquettes in the briquetting press, and these are then packed in sacks and stored before transport.

Reported annual wages for the different job categories in each of the three interviewed briquetting plants are shown in Table 4.21. The data correspond to actual wages paid in 2019, when the interviews were carried out.

Table 4.21. Reported annual wages for the job categories related to the briquetting process in each of the three interviewed briquetting plants, and average annual wages for each job category

Job category	Briquette producer 1		Briquette producer 2		Briquette producer 3		Average	
	KSh	$	KSh	$	KSh	$	KSh	$
Administration	Not available		522 000	5 161	Not available		522 000	5 161
Mill and briquetting press feeder	224 400	2 219	198 000	1 958	Not applicable		211 200	2 088
Conveyor feeder	Not applicable		Not applicable		105 696	1 045	105 696	1 045
Briquetting press operator	360 000	3 559	413 400	4 088	240 000	2 373	337 800	3 340
Packaging operator	Not applicable		Not available		105 696	1 045	105 696	1 045
Tractor driver	Not applicable		302 796	2 994	Not applicable		302 796	2 994
Maintenance technician	Not applicable		Not available		360 000	3 560	360 000	3 560
Briquetting plant supervisor	Not applicable		Not available		480 000	4 746	480 000	4 746
Briquetting plant manager	Not available		1 800 000	17 798	840 000	8 306	1 320 000	13 052

Briquette transport from the briquetting plant to the tea factory

The bagasse briquettes are transported in trucks with a load capacity between 10 to 12 tons in the case of small trucks or around 28 tons in the case of big trailers. The approximate reported average transport distance is 159 kilometres (see Indicator 23), and a driver and an assistant are involved in the transport. Information about the monthly wages of the driver and the assistant could not be gathered during the interviews with the briquetting plants. This was either because the company buying the briquettes typically covers transport costs, or because transport expenses are based on one specific delivery and the calculation of the monthly wage would not have been accurate. Therefore, the monthly wage was estimated from the average annual wage earning per employee in the transport and storage sector in 2016, which was KSh 1,203,430 ($11,905).

Briquette reception and storage at the tea factory

Tea factories have staff in charge of receiving and storing the biomass to be used in their boilers. When wood logs are received, these are stacked so that they dry easily. In the case of the briquettes, the normal practice is to carry out a quality check first, after which they are stored in a dry place until used in the boiler.

Boiler feeding and operation

Once the tea leaves are received in the factory and their quality has been checked, they are prepared for withering, a process in which moisture content is reduced by passing warm air through big tables on which the leaves are extended. After withering, the leaves are cut into pieces and, in the case of black tea preparation, go to the fermentation phase. Once the fermentation is completed, the tea is dried in rotary drum dryers. Large quantities of steam are used during withering and drying.

The three visited companies have very similar set-ups. Biomass is combusted in the boilers, which transforms liquid water into steam that is then used in the withering tables and in the rotary driers, in which steam is used to heat air in a heat exchanger that, in turn, dries the tea.

Jobs related to the boilers are boiler feeders, boiler operators and maintenance staff.

Data on annual wages collected during the interviews with the three tea factories that were visited are compiled in Table 4.22. This data correspond to actual wages paid in 2019, when the interviews were carried out.

Table 4.22. Reported annual wages for the job categories related to the briquetting reception, storage and usage in each of the three interviewed tea factories, and average annual wages for each job category

Job category	Case Study 1		Case Study 2		Case Study 3		Average	
	KSh	$	KSh	$	KSh	$	KSh	$
Stock keeper	360 000	3 560	Not applicable		Not available		360 000	3 560
Storage	360 000	3 560	480 000	4 746	Not available		420 000	4 153
Firewood supervisor	Not applicable		Not applicable		Not available		Not available	
Boiler feeder	360 000	3 560	300 000[a]	2 966	Not available		330 000	3 263
Boiler operator	360 000*	3 560	Not available		Not available		360 000*	3 560
Maintenance	360 000	3 560	Not available		Not available		360 000	3 560
Procurement	360 000	3 560	480 000	4 746	Not available		420 000	4 153

* Factory 1 did not report the specific salaries for every single job category but an average of the salaries received by the staff working with the reception, storage and utilization of briquettes.

[a] Factory 2 reported an average wage of 25,000 for the boiler feeders, but this varies slightly from worker to worker.

Wage comparison

Annual average wage earnings per employee within different sectors during the period 2013-2016 in Kenya are presented in Table 4.23. In 2016, the average annual earnings per employee in the private and public sectors was KSh 645,035.2 and increased 5.9 per cent with respect to 2015. The increase in average earnings between 2015 and 2016 was slightly higher for the public sector (6.4 per cent) compared to the private sector (5.7 per cent). Among the private sectors that recorded the highest increase in annual average earnings between 2015 and 2016 were Information and communication, wholesale and retail trade, repair of motor vehicles and motorcycles (8.8 per cent) and agriculture, forestry and fishing (7.8 per cent).

The average gazetted monthly basic minimum wage for the agricultural industry in 2016 was KSh 7,284 (Table 4.24) (KNBS 2018), corresponding to KSh 87,408 per year. Thus, annual average wage earnings for the employees working in the interviewed factories were all above the average minimum for 2016.

Table 4.23. Average annual wage earnings in KSh per employee, 2013-2016, and change between 2015 and 2016

	2013	2014	2015	2016	Change 2015-2016 (%)
Private sector					
Agriculture, forestry and fishing	218 637	230 717	254 274	274 049	7.8
Manufacturing	320 187	349 733	390 406.1	415 959	6.5
Electricity, gas, steam and air conditioning supply	1 125 666	1 247 238	1 399 604	1 463 986	4.6
Transport and storage	969 506	1 053 344	1 177 969	1 203 430	2.2
Professional, scientific and technical activities	816 100	861 867	940 331	996 639	6.0
Administrative and support service activities	1 181 397	1 236 543	1 363 246	1 393 880	2.2
Public administration and defence; compulsory social security	-	-	-	-	
Education	817 809	830 085	885 101	896 491	1.3
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	177 267	186 011	203 473	215 885	6.1
TOTAL private sector	500 065	537 670	595 211	629 323	5.7
Public sector					
Agriculture, forestry and fishing	347 891	367 655	394 286	416 034	5.5
Manufacturing	752 483	797 183	843 573	881 901	4.5
Electricity, gas, steam and air conditioning supply	1 231 708	1 261 782	1 315 696	1 346 867	2.4
Transport and storage	1 298 010	1 382 681	1 500 060	1 600 876	6.7
Professional, scientific and technical activities	560 096	590 358	628 540	659 876	5.0
Administrative and support service activities	-	-	-	-	
Public administration and defence; compulsory social security	461 100	481 382	522 748	551 311	5.5
Education	475 306	524 732	571 890	620 606	8.5
Activities of extraterritorial organizations and bodies	-	-	-	-	
TOTAL public sector	548 731	589 984	642 743	683 861	6.4
TOTAL private and public sector	514 630	553 137	608 991	645 035	5.9

Source: KNBS 2018

Table 4.24. Gazetted monthly basic minimum wages (KSh) for the agricultural industry, 2013-2017

Type of Employee	2013	2014	2015	2016	2017
Unskilled employees	4 854	4 854	5 437	5 437	6 416
Stockman, herdsman and watchman	5 606	5 606	6 279	6 279	7 409
Skilled and semi-skilled employees					
House servant or cook	5 542	5 542	6 207	6 207	7 324
Farm foreman	8 757	8 757	9 808	9 808	11 574
Farm clerk	8 757	8 757	9 808	9 808	11 574
Section foreman	5 669	5 669	6 350	6 350	7 492
Farm artisan	5 802	5 802	6 498	6 498	7 668
Tractor driver	6 153	6 153	6 891	6 891	8 131
Combine harvester driver	6 778	6 778	7 592	7 592	8 958
Truck driver or car driver	7 113	7 113	7 967	7 967	9 401
Average	**6 503**	**6 503**	**7 284**	**7 284**	**8 595**

Source: Adapted from KNBS 2018

In conclusion, the annual average wage earnings for the employees working in the interviewed factories were all above the average minimum for 2016. Skilled workers in the agricultural and manufacturer section have higher wages than unskilled workers. The majority of women working in the briquette factories are within the unskilled category and are hired under seasonal contracts; therefore these wages are not reported under national statistics.

CHARCOAL

The income generated is from the self-consumption of the charcoal by the producers, or from the direct sale of some part of the production by the producers or transporters.

In the case where the wood used to produce the charcoal is obtained illegally, mostly from public lands, charcoal prices do not reflect its real value. The production of charcoal takes place almost entirely in rural areas with a very low technological level, and it is considered an agricultural activity. Currently, most charcoal in Kenya is produced in traditional earth kilns (MEWNR 2013).

According to an analysis of the charcoal value chain in Kenya, revenue distribution varies greatly along the value chain. Revenues are concentrated in the hands of the vendors and transporters, which receive 41 per cent and 37 per cent of the total revenue, respectively. In contrast, the producers of wood and charcoal receive only 22 per cent (MEWNR 2013). Producers and consumers are the least beneficiaries of the whole value chain. This is due mainly to the informal nature of the sector, to the lack of functioning laws and regulations and to high levels of corruption and bribes (MEWNR 2013).

Establishing and strengthening regulations would contribute to the development of the charcoal sector. Companies or entities where employees could be hired and were able to receive an actual salary would improve working and payment conditions. Moreover, distribution of the revenues along the charcoal value chain could be forced to be more even.

As described in the National Charcoal Survey (Mutimba and Barasa 2005), there were a total of 200.000 charcoal producers in Kenya in 2005 and an additional 500,000 people involved in the charcoal trade. A market survey in Kitui County found that workers engaged in charcoal production received, on average, a daily remuneration of KSh 400 (Luvanda et al. 2016). Assuming that these workers would have been exclusively engaged in charcoal production on a full-time basis, they would have received a total of KSh 9,600 per month. Data collected during the interview with the charcoal producer association (CPA) are included in Table 4.25.

Table 4.25. Data compiled during the interview with the charcoal producer association (CPA), which pertains to a forest users and conservation association (FUCA) and in turn has several charcoal producer groups (CPGs)

	Case Study County 1
Number of associations (CPAs) per FUCA	**9**
Number of groups (CPGs) per CPA	**126**
Total number of people per FUCA	**4 410**
Monthly average charcoal production per FUCA (bags)	**25 000**
Estimated monthly average charcoal production per FUCA (tones)	**1 125**

4.11.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of findings

In general, the average annual earnings in Kenya increased by almost 6 per cent both in the private and public sectors in 2015-2016.

Earnings for most of the workers in the interviewed factories are above those of workers in the agriculture, forestry and fishing sector. Briquetting plant managers are the only workers whose wage earnings are above the annual average earnings for the private and public sectors.

The women involved in manual bagasse drying receive the lowest earnings in the entire value chain.

Practices and policies to improve sustainability

Through implementation of policies and regulations, better wage distribution among the different actors involved in the bagasse briquette value chain could be achieved.

Future monitoring

Performing the same wage analysis for other biomass briquettes sub-sectors as well as for other bio-fuels types would contribute to a better understanding, which in turn might develop useful information for policy makers.

As the situation changes in the value chain, for instance with more companies emerging, periodic analysis would provide monitoring.

CHARCOAL

Synthesis of findings

Revenues are concentrated in the hands of vendors and transporters. The wood and charcoal producers are the value chain actors that receive the lowest share of the revenues.

Establishing and strengthening regulations would contribute to the development of the charcoal sector. Companies or entities where employees could be hired and were able to receive an actual salary would improve working and payment conditions. Moreover, distribution of the revenues along the charcoal value chain could be forced to be more even.

Bribing of police is a daily practice that affects all actors in the value chain.

Practices and policies to improve sustainability

Implementation of the existing policies and rules would help to stabilize the charcoal sector, to balance the revenue distribution and to reduce unethical practices such as bribing police.

Future monitoring

Considering the changing environment for charcoal, not least caused by the moratorium on logging activities, monitoring of the charcoal value chain with regard to wages and their distribution would be very advisable.

4.11.6 References

Kenya National Bureau of Statistics (2018). *Economic Survey*. Nairobi. https://www.knbs.or.ke/download/economic-survey-2018/.

Luvanda, A.M., Kitheka, E., Oduor, N., Kyalo, E.M. and Githiomi, J. (2016). Impact and assesment of charcoal marketing system through communitty associations in Kitui County, Kenya. *Octa Journal of Environmental Research* 4(2), 86-91.

Ministry of Environment, Water and Natural Resources (2013). *Analysis of the Charcoal Value Chain in Kenya*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Mutimba, S. and M. Barasa (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainable Charcoal Industry in Kenya*. Energy for Sustainable Development Africa. Nairobi.

Onekon, W. A. and Kipchirchir, K.O. (2016). Assessing the effect of charcoal production and use on the transition to a green economy in Kenya. *Tropical and Subtropical Agroecosystems* 19, 327-335.

4.12 Indicator 12. Jobs in bioenergy sector

4.12.1 Definition

Net job creation as a result of bioenergy production and use, total (12.1) and disaggregated (if possible) as follows: (12.2) skilled/unskilled, (12.3) indefinite/temporary.
(12.4) total number of jobs in the bioenergy sector;
(12.5) percentage adhering to nationally recognized labour standards consistent with the principles enumerated in the ILO Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors

4.12.2 Measurement unit(s)

(12.1) number and number per MJ or MW
(12.2) number, number per MJ or MW, and percentage
(12.3) number, number per MJ or MW, and percentage
(12.4) number and as a percentage of (working-age) population
(12.5) percentages

4.12.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

Jobs in the bioenergy sector, and more specifically those related to the production of bagasse briquettes and their transport to and consumption by the tea industry, were studied.

Three briquetting plants, three tea factories, and one charcoal producers association (CPA) were interviewed to gather information about the jobs involved in the studied pathways. Reported job numbers were disaggregated into skilled/non-skilled and permanent/temporary where available. Based on the bagasse calorific value, 18.3 MJ/kg (García López 2016), and on the briquette production of each of the three briquetting plants, the number of employees per MJ was also estimated.

Additionally, published data were used.

CHARCOAL

Available literature as well as primary data collected during the field visits were used to develop this indicator.

It was also considered of relevance to analyse the jobs in the bagasse briquette value chain sector from a gender perspective.

4.12.4 Key findings

NATIONAL LEVEL

Kenya has so far ratified 49 International Labour Organization conventions, 6 of which have been denounced. Section 2(5) of the Constitution of Kenya provides that the general rules of international law shall form part of the law of Kenya, while Section 2(6) states that any treaty or convention ratified by Kenya shall form part of the law of Kenya under the Constitution (ILO 2013). Child labour is still one of the main social labour problems in Kenya. Table 4.26 shows the ratified International Labour Organization conventions that relate to working conditions, with links to the activities related to biomass production (Table 4.26).

Table 4.26. International Labour Organization conventions ratified by Kenya

No.	ILO Convention	Year ratified	In force
29	Convention concerning Forced or Compulsory Labour	1969	Y
87	Convention concerning Freedom of Association and Protection of the Right to Organise	1976	N
98	Convention concerning the Application of the Principles of the Right to Organise and to Bargain Collectively	1976	Y
100	Convention concerning Equal Remuneration of Men and Women Workers for Work of Equal Value	1963	Y
105	Convention concerning the Abolition of Forced Labour	1963	Y
111	Convention concerning Discrimination in Respect of Employment and Occupation	1969	Y
138	Convention concerning Minimum Age for Admission to Employment)	2001	Y
182	Convention concerning the Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour	2005	Y

Table 4.27. Number of jobs in the three interviewed briquetting plants, disaggregated into skilled/unskilled, permanent/temporary and female/male categories show the number of jobs (total and disaggregated into skilled/non-skilled, permanent/temporary and female/male categories) reported during the interviews conducted at the three briquetting plants and the three tea factories, respectively.

Table 4.27. Number of jobs in the three interviewed briquetting plants, disaggregated into skilled/unskilled, permanent/temporary and female/male categories

	Case study 1			Case study 2			Case study 3		
	Number	Percentage (%)	Number/ MJ (10^{-6})	Number	Percentage (%)	Number/ MJ (10^{-6})	Number	Percentage (%)	Number/ MJ (10^{-6})
TOTAL	44 - 84	100	6.7 - 13	55 - 56	100	3.1 – 1.8	26	100	8.5
Skilled	8	18 - 10	1.2	N/A	N/A	N/A	0	0	0
Unskilled	36 - 76	82 - 90	5.5 - 12				26	100	8.5
Permanent	14	32 - 17	2.1	51	91-93	2.9 – 1.7	26	100	8.5
Temporary	30 -70	68 - 83	4.6 - 11	4 – 5	7-9	0.13 – 0.28	0	0	0
Female	31 - 71	70 - 85	4.7 – 11	4	7	23 – 13	0	0	8.5
Male	13	30 - 15	2	51 - 52	93	3 – 1.7	26	100	0

Table 4.28. Number of jobs in the three interviewed tea factories, disaggregated into skilled/unskilled, permanent/temporary and female/male categories

	Case study 1		Case study 2		Case study 3	
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)
TOTAL	14	100	9	100	13	100
Skilled	1	7	6	67	2	15
Unskilled	13	93	3	33	11	85
Permanent	14	100	9	100	13	100
Temporary	0	0	0	0	0	0
Female	1	7	1	11	1	8
Male	13	93	8	89	12	92

Kenya became a member of the International Labour Organization (ILO) in 1964. In June 1998, the International Labour Conference adopted the ILO Declaration on Fundamental Principles and Rights at Work. All of the jobs identified in briquette production (from sugarcane bagasse) seem to follow the principles enumerated in this declaration (sub-indicator 12.4).

The following job categories related to the production and use of bagasse briquettes were identified during the interviews:

- Jobs related to the transport of bagasse from the sugar factory to the briquetting plant, included in the transport category.
- Jobs related to the sun drying of the bagasse, included in the briquette production category.
- Jobs related to the briquetting process, included in the briquette production category.

- Jobs related to the transport of the bagasse briquettes from the briquetting plant to the tea factory, included in the transport category.
- Jobs at the tea factory related to reception and storage of bagasse briquettes, included in the briquette consumption category.
- Jobs within the tea factory related to the boilers feeding and maintenance, included in the briquette consumption category.

Each of these job categories have been disaggregated into skilled/non-skilled, temporary/permanent and male/female predominated according to the information collected during the interviews (Table 4.29). In general, the informal sector is predominant in Kenya, accounting for around 80 per cent of the working population (KNBS 2018). Although most of the job categories related to the production, transport and consumption of bagasse briquettes in tea factories are permanent, there are still some job categories that are temporary (Table 4.29).

Table 4.29. Qualitative jobs data collected during interviews with the briquetting plants and the tea factories

Job category/description		Skilled	Unskilled	Temporary	Permanent	Male	Female
Transport	Truck driver	X			X	X	
	Truck assistant		X		X	X	
Production	Bagasse sun drying		X	X			X
	Mill and press feeders		X		X	X	
	Press operator	X			X	X	
	Maintenance	X			X	X	
	Plant manager	X			X	X	
	Administrative	X			X		X
	Packaging		X		X	X	
Consumption	Procurement	X			X	X	
	Receiving		X		X	X	X
	Feeding		X		X	X	
	Boiler operator	X			X	X	
	Maintenance	X			X	X	

The fuel use in the tea factories is related to tea production and to the thermal efficiency of the curing process. The thermal efficiencies to consider in the tea curing process are the thermal efficiencies of the boiler, of its heat exchanger, and of the rotary drum dryers used to cure the tea, as well as the heat losses on the pipping and intermediate stages. Therefore, the fuel demand might remain as-is as long as the tea production and facilities do not change. Today, most of the biomass required for the tea industries comes from tree plantations, which are either on the tea farms or on external land.

It is assumed that the jobs related to wood production would not disappear if bagasse briquettes gained greater presence in the energy mix of the tea industry. Trees could instead be sold to the timber industry, which would likely give farmers higher profits than from selling the trees to tea factories.

CHARCOAL

As described in the Forests (Charcoal) Regulations of 2009, charcoal producers have to organize and constitute charcoal producer associations (CPAs). Further, as the Forest Conservation and Management Act of 2016 describes, a forest association must contribute to and promote the sustainable conservation and management of the forest. Moreover, a forest association has the right to collect herbs, honey, timber, and firewood, among other forest products.

Most of the income-generating activities carried out in the charcoal value chain are on an informal basis (Table 4.30). The only activities that are considered formal are tree planting, pruning and harvesting. However, in most cases, the wood used to produce the charcoal does not come from plantations or other managed tree systems.

Table 4.30. Jobs related to income-generating activities in the charcoal value chain from agroforestry and used by households

Income-generating activity	Jobs	Type of wage employment	
		Formal	Informal
Tree production	Planting Pruning Thinning/Harvesting	X X X	
Charcoal production	Kiln maker Kiln maker assistant		X X
Transporter	Truck driver Truck assistant		X X
Wholesalers	Trader Trader assistant		X X
Retailers	Vendor Vendor assistant		X X

Regarding sub-indicator 12.4, slavery, child labour or any other type of labour not recognized in the ILO Declaration on Fundamental Principles and Rights at Work are not present in any of the activities developed within the studied value chain. This is despite the fact that the charcoal sector is very informal. Nevertheless, in rural areas, it is common to see children involved in kiln preparation and charcoal production. Children typically do these activities outside school hours, and the produced charcoal might be for own-consumption or to help contribute to the household's economy.

The role of women in the charcoal value chain is mainly related to charcoal burning and retail. Women are involved in the collection of small branches, soil, and water for the kiln preparation, and in the packaging of the final product. In some studies, the presence of women as wholesalers in the sector has been discussed, but this has been estimated to be much lower than men, in terms of number and also the volume of the commercialized product.

Additionally, the charcoal sector is often monopolized by a few actors involved in the transport and wholesaling, activities that are heavily dominated by men[4].

A recurrent argument that appears in the literature regarding charcoal in sub-Saharan Africa in general, and in Kenya in particular, is that the different actors involved in the charcoal value chain have to bribe police as a regular practice (Johnson et al. 2018; MEWNR 2013; World Bank 2011). This enormous problem mostly affects the most vulnerable people in society. Most charcoal users struggle economically to afford the daily purchase of charcoal. Bribing does end up affecting the final price of the retailed charcoal and hurts the charcoal value chain, which is inefficient and highly polluting by nature.

On the geopolitical level, it has been found that vast amounts of charcoal are exported from Central and East African countries like Kenya to countries such as Egypt, Yemen, Saudi Arabia, Oman, the United Arab Emirates and Lebanon. This distribution chain is controlled by the terror group Al Shabaab and has been identified as one of their primary sources of funding (Nellemann et al. 2014).

Employment in Kenya increased 5.4 per cent in 2016, from 15.2 million people in 2015 to 16 million in 2016. The informal sector constituted 83.2 per cent of the total employment in 2016 (KNBS 2018). That same year, the informal sector created 747,200 new jobs, 30,700 more than in 2015, whereas the formal sector created only 84,800 new jobs, 43,200 less than in 2015.

The shares of jobs in the formal and informal sectors remained relatively stable between 2013 and 2016. In 2013, the formal sector had record employment of 2,366,900 people, accounting for 17.5 per cent of the working population, whereas the informal sector had 11,150,100 people, or 82.5 per cent of the working population. In 2016, employment in the formal sector increased slightly to 2,686,000, or 16.8 per cent of the working population, and employment in the informal sector increased to 14,097,500, or 83.4 per cent of the working population.

The number of new jobs created between 2013 and 2016 decreased for the formal sector but increased notably for the informal sector.

Between 2015 and 2016, total wage employment in the private sector increased from 1,759,600 people to 1,817,200 people, corresponding to 57,600 new jobs and an increase of 3.3 per cent (Table 4.31). Agriculture, forestry and fishing contributed the highest wage employment in 2016, with a share of 16.2 per cent of total private sector employment that year.

Table 4.31. Wage employment by Industry in the private sector, 2013-2016

Industry	2013	2014	2015	2016
	thousands			
Agriculture, forestry and fishing	299.9	290.6	294.0	294.5
Transport and storage	58.8	62.1	64.8	67.8
Professional, scientific and technical activities	59.4	60.7	62.6	64.8
Administrative and support service activities	4.8	4.9	5.2	5.4
TOTAL WAGE EMPLOYMENT PRIVATE SECTOR	1 599.8	1 669.4	1 759.6	1 817.2

Source: Adapted from KNBS Economic Survey 2018

In the agriculture, forestry and fishing sector, the number of male employees was double that of female employees in 2016 (Table 4.32). In the manufacturing sector, the number of male employees was five-fold the number of female employees, and in the transport and storage sector, the number of males was more than triple the number of women. In the administrative and support service activities sector, the number of male employees was nearly 10 times more than the number of female employees. These data only reflect the formal sector, however, and the informal sector is dominated by women (Lambro and Piana 2006).

Table 4.32. Wage employment by industry and gender, 2016

Industry	Male	Female	Total
	thousands		
Agriculture, forestry and fishing	225.1	111.6	336.7
Manufacturing	252.1	48.7	300.8
Transport and storage	65	20.8	85.8
Administrative and support service activities	4.9	0.5	5.4

Source: Adapted from KNBS Economic Survey 2018

In addition to the gender gap in wage employment in the formal sector, there is also a gender salary gap (Kabubo-Mariara 2003). In rural areas in particular, such gender disparity in wage employment

and remuneration has terrible consequences. Women in rural areas are among the poorest in Kenyan society (Suda 2002).

In 2016, the number of males with permanent employment was nearly double that of females (Table 4.33). In general, both for males and the females, the permanent wage employment rate is around 80 per cent.

Table 4.33. Permanent and temporary wage employment by gender, 2016

	Male	Female	Total
		thousands	
Regular/Permanent	1 268.3 (75.7%)	702.7 (79.9%)	1 971 (77.2%)
Casual/Temporary	406.2 (24.3%)	176.4 (20.1%)	(22.8%)
TOTAL	1 674.5	879.1	2 553.6

Source: Adapted from KNBS Economic Survey 2018

4.12.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of findings

In general, the informal sector is predominant in Kenya, accounting for around 80 per cent of the working population. The role of women in the bagasse briquette value chain is limited to sun drying of bagasse.

Practices and policies to improve sustainability

National strategies aimed at consolidating the biomass briquettes sector will contribute to the development of the industry, the transformation of the sector to more formal-based employment and to the promotion of women within the value chain.

Future monitoring

As important changes in the bagasse briquettes bioenergy sub-sector take place, such as modification or exchange of the boilers, growth in the number of tea factories or the use of other types of agricultural residues in the production of briquettes, measurements of jobs will be very useful to assess how the sector is developing.

CHARCOAL

Synthesis of findings

Most of the workers in the Kenyan charcoal sector are employed on an informal basis. According to published data, most of the sectors are dominated by men. Especially in rural areas, unemployment and lower salaries among women are very common, which leads to terrible economic and social consequences.

Practices and policies

Regulation of the charcoal sector would be a positive strategy to reduce the gender gap in the charcoal sector.

Future monitoring

As regulations are implemented, future monitoring is crucial to assess whether the implementation of such regulations is facilitating the desired effect on the sector.

4.12.6 References

García López, N. (2016). *Biomass Utilization for Energy Purposes in Kenya: Fuel Charactersitics and Thermochemical Properties*. BSc thesis. Umeå University, Sweden.

International Labour Organization (2013). Kenya Decent Work Country Programme 2013-2016. http://www.ilo.org/public/english/bureau/program/dwcp/download/kenya.pdf.

Johnson, O.W., Wanjiru, H., Taylor, R. and Johnson, F.X. (2018). *Overcoming Barriers to Sustainable Charcoal in Kenya*. SEI Discussion Brief.

Kabubo-Mariara, J. (2003). *Wage Determination and the Gender Wage Gap in Kenya: Any Evidence of Gender Discrimination?* AERC Research Paper 132. Africa Economic Research Consortium. Nairobi.

Kenya National Bureau of Statistics (2018). *Economic Survey*. Nairobi.

Lambrou, Y. and Piana, G. (2006). *Energy and Gender in Rural Sustainable Development*. Food and Agriculture Organization of the United Nations. Rome.

Laws of Kenya (2016). Forest Conservation and Management Act.

Ministry of Environment, Water and Natural Resources (2013). *Analysis of the Charcoal Value Chain in Kenya*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Nellemann, C., Henriksen, R., Raxter, P., Ash, N. and Mrema, E. (Eds.) (2014). *The Environmental Crime Crisis: Threats to Sustainable Development from Illegal Exploitation and Trade in Wildlife and Forest Resources.* A UNEP Rapid Response Assessment. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal.

Republic of Kenya (2009). *The Forests (Charcoal) Rules, 2009*. Nairobi.

Suda, C. (2002). Gender disparities in the Kenyan labour market: Implications for poverty reduction. *Nordic Journal of African Studies* 11(3), 301-321.

World Bank (2011). *Wood-based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches*. Africa Renewable Energy Access Program. https://doi.org/10.1596/26149.

4.13 Indicator 13. Change in average unpaid time spent by women and children collecting biomass

4.13.1 Description

(13.1) Change in average unpaid time spent by women and children collecting biomass as a result of switching from the traditional use of biomass to modern bioenergy services.

4.13.2 Measurement unit(s)

Hours per week per household, percentage

4.13.3 Overall methodology of the implementation

Five, three and six studies on sourcing firewood from forests, trees on farm and improved stoves, respectively, were reviewed. This was to determine the time saving by switching from the conventional practice of sourcing firewood from the forest and using a traditional three-stone open fire to an improved system of sourcing from trees on-farm and using improved stoves.

Existing data from household surveys were used to determine the amount of time and money that would be saved by switching from conventional practices to the improved system. The data are from rural areas, where firewood is mainly collected from forests for household use. Distances to sources of firewood in the forests increase with population increase, as residues at the edge are depleted and women have to travel further interior (Duguma et al. 2014). The saved time could alternatively be spent on income-generating activities, leisure or school activities for children.

Different practices occur in sourcing firewood from trees on farm that include: 1) one trip purposely made per week, 2) women carrying firewood as they go home after working in the farms and 3) the use of prunings of multipurpose trees such as timber and fruit trees where few branches of the trees are removed annually or once in two years depending on the tree species and the firewood carried to homesteads in a few days. For comparison purposes, this study used the first option. Households that do not have young boys to prune the trees or young girls to carry firewood from the farms to the homestead pay young men or women respectively to do these chores.

The data available on time spent on firewood collection is per household and does not categorize the time spent by women, children, and men. The assumption made in this work is that women are the main firewood collectors. For example, at Gazi Bay in coastal Kenya, 95 per cent of the firewood collectors were reported to be women and children (Jung and Huxham 2018). Data at the national level are missing, and some of the available data from case studies fail to indicate whether the time is for a round-trip of firewood collection.

4.13.4 Key findings

Results

From the five case studies, households spent 3 to 8 hours, or 4.2 hours on average, on a round-trip to collect one load of firewood from the forest (Table 4.34). From the three case studies where households sourced firewood from trees on the farms, they spent 1 to 2 hours, or 1.5 hours on average, on a round-trip for one load of firewood collection. If the five case studies on households sourcing firewood from the forest start practicing agroforestry and sourcing all of their firewood on-farm, they could save an average of 2.7 hours per load of firewood collected, or around 64 per cent time saving.

Table 4.34. Distances covered and time spent in firewood collection by region

Site	Distance from forest (km)	Time to collect firewood (hour)		Source
		Forest	On-farm	
Kibugu, Embu	8	4	2	Njenga et al. 2019
Kereita, Kiambu	6	3	1	Njenga et al. 2019
Matuga, Kwale	N/A	3	1.4	Gitau et al. 2019a, 2019b
Gazi Bay	1.8	3.1	N/A	Jung and Huxham 2018
Dadaab	N/A	8	N/A	Bizzari 2010
Average	**5.3**	**4.2**	**1.5**	

Similarly, if the households from the six case studies in Table 4.35 moved from use of the traditional three-stone open fire to improved cookstoves, they would save 33.2 per cent of firewood on average. This implies a shift in annual consumption from 2,701 kilograms to 1,806 kilograms. This annual consumption is calculated from the usage of one woman-load of 52 kilograms per week, as stated by women, or the equivalent of 1.74 kilograms per capita per day. When per capita was established through women using firewood from a pile of known amount, this changed to 1 kilogram, and the difference may have been caused by a shift in use during the measuring process or low precision in women’s estimation (Njenga et al. 2019).

Table 4.35. Fuel saving from use of improved stove compared to three-stone open fire

Place	Stove	% fuel saving	Source
Kiambu	Kuniokoa	46	Njenga et al. 2018
Kwale	Gasifier*	32	Gitau et al. 2019
Embu	Gasifier*	40	Njenga et al. 2016
Embu	Kuni moja	20	Njenga et al. 2016
Rural Kenya	Rocket mud	34	Ochieng et al. 2013
Western Kenya	Gasifier	27	Torres-Rojas et al. 2014
Average		**33.2**	

* For the gasifier stove, the char produced was considered as fuel.

A combination of sourcing firewood from trees on-farm and the use of improved stoves saves in total 76 per cent of time, as shorter trips are made and less fuel is used by a household. This is as a result of fewer, shorter trips for firewood collection. Although not calculated, more time saving would be achieved through the application of a regular annual or biennial pruning regime.

Interpretation of these results as regards sustainability

Through the adoption and sustained use of improved cookstoves, integrated with on-farm sourcing of firewood, households can save 33.2 per cent of fuel (from 2,704 kilograms to 1,806 kilograms per year) and 76 per cent of time spent sourcing the fuel. Sourcing firewood on-farm translates into reduced time spent on firewood collection by 64 per cent due to the shorter distance walked to firewood collection sites.

For example, in Kenya's rural highlands and coastal region, 40 per cent of the households exclusively depended on agroforestry for firewood supply (Njenga et al. 2016; Gitau et al. 2019a). In Murang'a County in Kenya, over 90 per cent of households source firewood from multipurpose trees on the farms (Githiomi et al. 2012). In monetary value, weekly firewood collection is reduced by 17 weeks resulting in KSh 5,100, ($51) gained at a daily wage of KSh 300 ($3) and a KSh 300 ($3) Kenya Forest Service levy for three months.

Further unquantified improved quality of life would result from not carrying heavy loads through rough terrain in forests and an improved kitchen environment. Ecological resilience will also accrue from reduced forest disturbance.

4.13.5 Conclusions and recommendations

Synthesis of the findings

The use of prunings from trees on farms, integrated with the use of more-efficient improved cookstoves, is a promising innovation for reducing women's drudgery in sourcing firewood and reducing the health risks associated with household air pollution. Households could develop a pruning regime to help manage the trees on their farms and to have the firewood available from their farms all year round. This integrated cooking system should be promoted among rural households through capacity development on suitable multipurpose trees for the right purpose and right place while working with the private sector that promotes improved cookstoves. Households should also be advised on drying wood well to reduce household air pollution. The initiative should be integrated in the country's agendas on gender equality, cleaner cooking and climate change and should consult end users.

Practices and policies to improve sustainability

Households need to shift from using traditional three-stone open fires to improved cookstoves that are efficient and hence use less fuel and produce less emission. There is a need to grow agroforestry

trees on household farms to reduce the need to go into the forest to collect firewood, which is a time-consuming and life-threatening exercise. Incentives should be given for enhanced uptake of such technologies with training and follow-up, putting into consideration the user's needs and preferences. However, a complete shift from the three-stone open fire has not been achieved as households stack different stoves (Gitau et al. 2019) and hence there is need for improvement of the three-stone open fire.

Future monitoring

There is a need to monitor improvements in women's and households' well-being and the ecological gains/benefits accruing to forests, farms, landscapes and climate. There is a need for a national survey on labour data disaggregated by gender and age on firewood collection supported with cost of labour to quantify opportunity cost. Actual measurements using geographic information systems and spring balances are recommended to establish distances travelled on a round-trip of firewood collection and amounts of firewood transported respectively. In-depth studies are also required on the types of stoves being used, their fuel use efficiency and emissions. This information will be useful in supporting government programmes on agroforestry for gender equality, firewood supply, cleaner cooking, and climate change and forest management.

4.13.6 References

Bizzarri, M. (2010). *Safe Access to Firewood and Alternative Energy in Kenya*: *An Appraisal Report* World Food Programme and Women's Refugee Commission. Rome.

Duguma, A., Minang, P., Freeman, O. and Hager, H. (2014). System-wide impacts of fuel usage patterns in the Ethiopian highlands: potentials for breaking the negative reinforcing feedback cycles. *Energy for Sustainable Development* 20, 77-85.

Gitau, J.K. (2019). *Assessment of Biomass Cooking Systems and Improvement Through Micro Gasification in Small-Holder Farms: A Case of Kwale County, Kenya*. PhD Thesis. University of Nairobi, Kenya.

Gitau, J.K., Mutune, J., Sundberg, C., Mendum, R. and Njenga, M. (2019). Implications on livelihoods and the environment of uptake of gasifier cook stoves among Kenya's rural households. *Applied Science* 9, 1205.

Githiomi, J.K., Mugendi, D.N. and Kung'u, J.B. (2012). Analysis of household energy sources and wood fuel utilization technologies in Kiambu, Thika and Maragwa districts of Central Kenya. *Journal of Horticulture and Forestry* 4(2), 43-48.

Jung, J. and Huxham, M. (2018). Firewood usage and indoor air pollution from traditional cooking fires in Gazi Bay, Kenya. *Bioscience Horizons* 11. 10.1093/biohorizons/hzy014.

Njenga, M., Iiyama, M., Jamndass, R., Helander, H., Larsson, L., de Leeuw, J., Neufeldt, H. et al. (2016). Gasifier as a cleaner cooking system in rural Kenya. *Journal of Cleaner Production* 121, 208-217.

Njenga, M., Gitau, J.K., Iiyama, M., Jamnadassa, R., Mahmoud, Y. and Karanja, N. **(**2019**)**. Innovative biomass cooking approaches for sub-Saharan Africa. *African Journal of Food, Agriculture, Nutrition and Development* 19(1), 14066-14087. http://ajfand.net/Volume19/No1/BLFB1031.pdf.

Ochieng, C.A., Tonne, C. and Vardoulakis, S. (2013**).** A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya. *Biomass and Bioenergy* 58, 258-266.

Torres-Rojas, D., Lehmann, J., Hobbs, P., Joseph, S. and Neufeldt, H. (2014). Biomass availability, energy consumption and biochar production in rural households of Western Kenya. *Biomass and Bioenergy* 35, 3537-3546.

4.14 Indicator 14. Bioenergy used to expand access to modern energy services

4.14.1 Definition

(14.1) Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of (14.1a) energy and (14.1b) numbers of households and businesses.
(14.2) Total number and percentage of households and businesses using bioenergy, disaggregated into modern bioenergy and traditional biomass.

4.14.2 Measurement unit(s)

(14.1a) Modern energy services can take the form of liquid fuels, gaseous fuels, solid fuels, heating, cooling and electricity. A change in access to each of these forms of modern energy can be measured in MJ per year and this is preferable in order to allow comparison of different forms of energy service, but each may also be measured in appropriate units of volume or mass per year, which may sometimes be more convenient, such as litres/year or MJ/year for liquid fuels, tons/year or MJ/year for solid fuels, etc.
(14.1b) number and percentage
(14.2) number and percentage

4.14.3 Overall methodology of the implementation

The methodology applied in this indicator was a mix of a secondary data search and annual bioenergy demand calculation based on 2015 Kenya statistics. Data were sourced from various sources and surveys like the Ministry of Environment and Forestry report for 2013 and the Kenya National Integrated Household Survey report of 2015. As per the GBEP indicators description, the household perspective has more cooking events as compared to heating; in this case, the description focused on cooking. The indicator focused on the total amount and percentage of increased access to modern energy services. Estimation of annual bioenergy consumption was based on identification of the total activity level multiplied by energy intensity, as presented below.

4.14.4 Key findings

Modern energy access in households is dominated by liquefied petroleum gas (LPG). Modern bioenergy access via biogas, briquettes and pellets remains limited. Improved cookstoves could be considered to be modern bioenergy solutions if the efficiency of the stoves is high enough (higher than 20-30 per cent) and if their flue gases are released distant from their users, according to the GBEP definition.

In urban areas, 30 per cent of all households use kerosene for cooking, especially low-income households (KNBS 2018). According to a Ministry of Environment report, 82 per cent of urban households use charcoal for cooking (MEWNR 2013a). However, around 28 per cent use LPG for cooking. It was logically argued that households using kerosene and LPG also use charcoal, although at lower intensity. Tables 4.36 to 4.38 illustrate the shares of urban and rural households adopting various fuels and technologies.

Table 4.36. Access to modern energy services in urban and rural households in Kenya

Access to modern energy services	Share		Energy use per year	Units
	Urban (%)	Rural (%)		
Electricity	2.0	0.3	459	kWh/household/year
LPG*	27.7	2.5	99.9	kg/household/year
Biogas	0.3	0.2	1 093	cubic metre/household/year
Briquettes and pellets	2.0	0.0	-	

* Not considered as a clean fuel.
Source: KNBS 2018; MoE 2002; MEWNR 2013b

Table 4.37. Access to energy services in rural and urban households by fuel source in Kenya

Fuel	Households	
	Urban (%)	Rural (%)
Firewood	16.2	84.3
Charcoal	82.0	8.9
Twigs and agri-residues	0.7	1.5
Electricity	2.0	0.3
LPG	27.7	2.5
Biogas	0.3	0.2
Kerosene	29.5	2.3
Briquettes and pellets	2.0	0.0
LPG and charcoal	27.7	2.5
Kerosene and charcoal	29.5	2.3

Source: KNBS 2018

Table 4.38. Share of energy technologies in urban and rural households in Kenya

Cooking technology	Households		Final energy intensity	
	Urban (%)	Rural (%)		
Traditional three-stone fire	13.7	71.7	2 093	kg wood/household/ year
Improved wood stove	2.3	12.8	1 675	kg wood/household/ year
Traditional metal charcoal stove	13.5	5.7	593	gg charcoal/household/year
Kenya Ceramic Jiko	9.3	3.7	474.4	kg charcoal/household/ year
Electric stove	2.0	0.3	459	kWh/household/year
LPG cooker	27.7	2.5	99.9	kg/household/year
Biogas stove	0.3	0.2	1 093	cubic metres/household/year
Kerosene stove	29.5	2.3	221.4	litres/household/year

Source: KNBS 2018; MoE 2002; MEWNR 2013b

Charcoal used in a sustainable way, including in modern and improved cookstoves, is also considered sustainable according to the indicator. From the various literature sources, only 9.3 per cent of households in urban areas used improved charcoal stoves and 13.5 per cent used improved firewood stoves.

4.14.5 Conclusions and recommendations

Synthesis of result

As urbanization in Kenya increases at a rate of 4.1 per cent, charcoal use is expected to nearly double in the business-as-usual scenario. Whereas charcoal from farm forestry and rangeland can be considered as sustainable, the conversion technologies are largely unsustainable. Moreover, with the rising population in urban areas, firewood demand for charcoal production will be much higher than firewood demand for direct use with the current conversion kilns and stoves.

Policy practice to improve sustainability

The adoption of and access rate for modern and improved bioenergy services is still very low in spite of these technologies being available. This could largely be attributed to financial and social cultural attitudes. It is a national challenge to establish an effective business model to increase the adoption rates.

Future research

Data are very scant on the adoption of improved charcoal kilns and stoves and on verifiable intensity of use . An area of further research is to ascertain actual households using various energy services and technologies. Socio-technical research should be advanced to understand the underlying reasons for slow adoption. Most researchers refer to the Ministry of Energy report of 2002 for energy intensity, which is considered to be an outdated source and could be misleading regarding people's evolving behaviour and cultural practices.

4.14.6 References

Kenya National Bureau of Statistics (2018). *2015/2016 Integrated Household Budget Survey (KIHBS).* Nairobi.

Ministry of Energy (2002). *Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small-scale Industries and Service Establishments.* Final report. Nairobi. P. 160.

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of Demand and Supply of Wood Products in Kenya Study.* Nairobi.
http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%2Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Ministry of Environment, Water and Natural Resources (2013b). *Analysis of the Charcoal Value Chain in Kenya.* Nairobi.
http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

4.15 Indicator 15. Change in mortality and burden of disease attributable to indoor smoke from solid fuel use

4.15.1 Definition

(15.1) Change in mortality and burden of disease attributable to indoor smoke from solid fuel use
(15.2) Changes in these as a result of the increased deployment of modern bioenergy services, including improved biomass-based cookstoves.

4.15.2 Measurement unit(s)

Percentages

4.15.3 Overall methodology of the implementation

A desktop study on the change in mortality and burden of disease attributable to the exposure to household air pollution resulting from the use of solid fuel was done using available literature and data. Data from several organizations was gathered, including the Kenya National Bureau of Statistics, the World Health Organization, the World Bank and the International Energy Agency. The indicator is based on data from 2016.

Public health statistics often refer to attributable mortality and burden of disease in total numbers or percentage of the population. The burden of disease is a concept used to describe death and loss of health due to diseases, injuries and risk factors (WHO 2014, 2016). A common approach to estimate the burden of disease is by adding together a) the number of years of life a person loses (YLL) and b) the number of years that a person lives with disability caused by the disease (YLD). Adding together YLL and YLD gives the disability-adjusted life-years (DALYs), an estimate of the burden of disease that represents the loss of one year of life lived in full health (WHO 2019a). The number of deaths and DALYs are presented in total numbers and as age-standardized death and DALY rates (per 100,000 people).

The study considered the change in mortality and burden of disease by gender and setting (urban, peri-urban and rural).

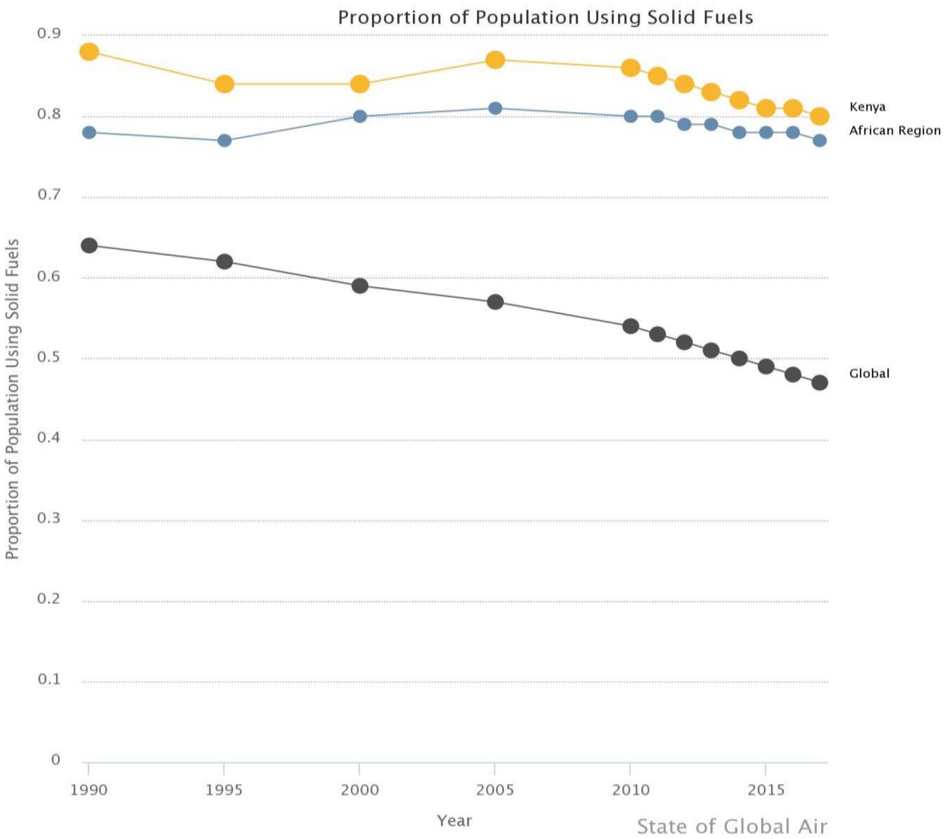
4.15.4 Key findings

Use of solid fuels

Globally, 2.5 billion people rely on the traditional use of solid fuels such as unprocessed firewood, cow dung, coal, charcoal and crop residues to meet their cooking and heating needs (IEA 2017). In sub-Saharan Africa around 80 per cent of the population uses solid fuels for cooking, while in Kenya the figure has declined to 70 per cent (Ministry of Energy and Clean Cooking Alliance 2019). The bioenergy is often in rudimentary and inefficient stoves with no or poorly operating chimneys (HEI 2018).

At a global scale, the share of the population that relies on solid fuels has decreased in the last couple of decades but remains around 50 per cent (HEI 2018). In contrast, in the case of sub-Saharan Africa, the proportion of the population using solid fuels in 2017 was very similar to that in 1995 (Figure 4.16).

Figure 4.16. Proportion of population using solid fuels globally (black), in sub-Saharan Africa (blue) and in Kenya (yellow), 1990-2017



Source: HEI 2019

Stove and fuel characteristics related to health impacts

From a technological point of view, the cookstoves used to combust biomass energy (e.g., wood logs, wood sticks, twigs, briquettes, and pellets) can be categorized into:

- *Three-stone fire:* This is the traditional set-up. Wood sticks and logs are combusted in the space created between three stones placed on the ground.
- *Rocket stove:* The technological principle is to create a draft to conduct the flames towards the bottom of the pot.
- *Gasifier stove:* Gasifier stoves use the principle of gasification to transform the energy contained in the fuel into heat.

In addition, charcoal is widely used for cooking and heating purposes. Charcoal is often combusted in traditional charcoal stoves or in improved charcoal cookstoves.

Within the cookstoves that use woody biomass, the highest emission factors are observed for the three-stone fire, followed by the rocket stoves and the gasifiers (García López 2017). Both particulate matter and gases are emitted when biomass is combusted in cookstoves. The highest emissions from cookstoves that use woody biomass are the particulate matter emissions, whereas in the case of the cookstoves that use charcoal, the highest emitted component is carbon monoxide (Obeng et al. 2017).

Mortality and burden of disease attributable to the usage of solid fuels

In 2016, household air pollution from combustion of solid fuels was responsible for 1.7 million deaths and 62 million DALYs worldwide (HEI 2019). In Kenya, the estimated number of deaths and DALYs attributable to household air pollution from solid fuels was 13,900 and 662,400, respectively (HEI 2018).

The World Health Organization, on the other hand, reports a slightly higher number of deaths attributable to household air pollution in 2016 in Kenya, at 15,140, of which 7,523 were males and 7,617 were females (WHO 2019b).

Age-standardized death and DALY rates attributable to household air pollution have sharply decreased during the last couple of decades. In Kenya, death rates due to household air pollution dropped from 109 in 1990 to 68 in 2016, whereas DALY rates decreased from 3,620 to 1,910 during the same period (HEI 2018).

Causes of deaths attributable to household air pollution – specific health conditions and diseases

Evidence from epidemiological studies has shown that exposure to smoke from incomplete combustion of solid fuels is linked with a range of conditions, including acute and chronic respiratory diseases. An estimated 15,140 deaths were attributable to household air pollution in Kenya in 2016, according to the World Health Organization (WHO 2019b). Of these, 67 per cent were attributable to lower respiratory infections in young children (under 5 years), followed by ischaemic heart disease in adults (above 25 years) (13 per cent), stroke in adults (12 per cent), chronic obstructive pulmonary disease in adults (7 per cent) and trachea, bronchus and lung cancers in adults (1.5 per cent) (Table 4.39 and Figure 4.17).

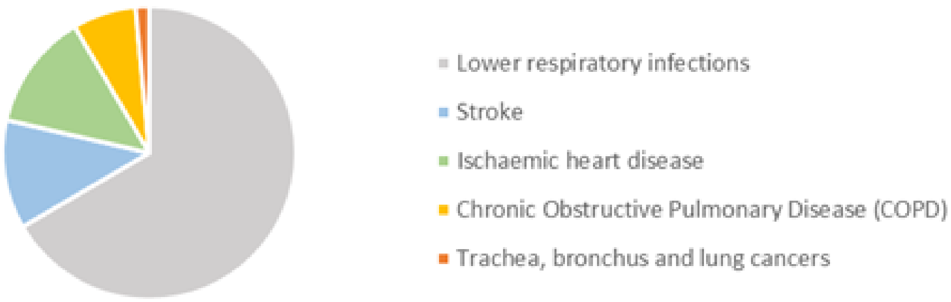
Respiratory infections are common in Kenya. In 2015-2016, 7.4 per cent and 3 per cent of the population that reported being sick/injured were diagnosed with upper and lower respiratory infections, respectively (Table 4.40).

Table 4.39. Deaths attributable to household air pollution in Kenya, 2016

Cause	Both sexes	Male	Female
Total	*15140*	*7 523*	*7 617*
Lower respiratory infections	10 083 (66.6%)	5 125	4 957
Trachea, bronchus, lung cancers	229 (1.5%)	126	103
Ischaemic heart disease	1 954 (12.9%)	997	957
Stroke	1 810 (12%)	790	1 020
Chronic obstructive pulmonary disease	1 064 (7%)	484	580

Source: WHO 2019b

Figure 4.17. Shares of deaths attributable to household air pollution by disease in Kenya, 2016



Source: Adapted from WHO 2019b

Table 4.40. Share of the population that reported being sick/injured by type of sickness/injury and residence (national, rural and urban), 2015/2016

	National	Rural	Urban
Upper respiratory infection	7.4	7.9	6.3
Lower respiratory infection	3	2.3	4.4
Asthma	1.2	1.4	1
Burn	0.3	0.3	0.4
Cancer	0.2	0.2	0.3
Other	8.9	9.3	8

Source: KNBS 2018. Adapted from the Basic Report based on 2015/2016.

4.15.5 Conclusions and recommendations

Synthesis of the findings

There seems to be some data discrepancy regarding the gender distribution of the deaths attributable to household air pollution in Kenya.

Practices and policies to improve sustainability

National action plans and policies exist in Kenya aiming to reduce the health effects of household air pollution. However, concrete interventions such as education and economic incentives that promote stoves with lower emission factors would contribute to reducing the health effects on the Kenyan population.

Future monitoring

Further comprehensive studies would help clarify the situation regarding the gender distribution of deaths attributable to household air pollution.

4.15.6 References

García López, N. (2017). *Fine Particle Emissions from Biomass Cookstoves*. MSc thesis, Umeå University, Sweden.

Health Effects Institute (2018). *State of Global Air 2018*. Special report. Health Effects Institute. Boston.

Health Effects Institute (2019). *State of Global Air 2019*. https://www.stateofglobalair.org/data. Accessed May 27, 2019.

International Energy Agency (2017). *Energy Access Outlook 2017: From Poverty to Prosperity*. World Enegry Outlook Special Report. https://doi.org/10.1787/9789264285569-en.

Kenya National Bureau of Statistics (2018). *Economic Survey 2018*. Nairobi. https://www.knbs.or.ke/download/economic-survey-2018/.

Ministry of Energy and Clean Cooking Alliance (2019). *Kenya Cooking Sector Study: Assessment of the Supply and Demand of Cooking Solutions at the Household Level*. https://www.eedadvisory.com/wp-content/uploads/2019/11/moe-2019-cooking-sector-study-.pdf

Obeng, G.Y., Mensah, E., Ashiagbor, G., Boahen, O. and Sweeney, D.J. (2017). Watching the smoke rise up: Thermal efficiency, pollutant emissions and global warming impact of three biomass cookstoves in Ghana. *Energies* 10, 1-14. https://doi.org/10.3390/en10050641.

World Health Organization (2014). *Guidelines for Indoor Air Quality: Household Fuel Combustion*. Geneva.

World Health Organization (2016). *Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children*. Geneva.

World Health Organization (2019a). About the Global Burden of Disease (GBD) project. http://www.who.int/healthinfo/global_burden_disease/about/en/. Accessed 18 May 2019.

World Health Organization (2019b). Global Health Observatory Data Repository. http://apps.who.int/gho/data. Accessed 24 May 2019.

4.16 Indicator 16. Incidence of occupational injury, illness and fatalities

4.16.1 Definition

(16.1) Incidences of occupational injury, illness and fatalities in the production of bioenergy in relation to comparable sectors.

4.16.2 Measurement unit(s)

Number/ha (for comparison with other agricultural activities) or number/MJ or MW (for comparison with alternative energy sources).

4.16.3 Overall methodology of the implementation

Several organizations were contacted to gather secondary data to include in the development of this indicator, among them the Ministry of Labour and Social Protection (State Department of Labour), Health Safety Environment (HSE) East Africa, the International Labour Organization and ILO Kenya. Unfortunately, none of these organizations provided any information regarding the incidence of occupational injuries and fatalities in Kenya.

Data on occupational injuries, illness and fatalities in Kenya are not publicly available for consultation, either because the data are non-existent or because organizations and companies are not willing to share it. ILOSTAT, the world's leading source of labour statistics, affiliated with the International Labour Organization, has no available data on safety and health at work for Kenya (ILO 2019).

In 2012, the Government of Kenya, through the Ministry of Labour in line with the International Labour Organization, developed the National Occupational Safety and Health Policy (GoK 2012), an important tool to ensure safety at workplaces. The Occupational Safety and Health Act requires that data on injuries and fatalities be reported to relevant offices; however, most companies hide the information to avoid compensating the injured people or families.

Charcoal is not produced in a factory setting but rather in a decentralized manner in rural settings. As such, charcoal production is seen as an alternative agricultural activity that is carried out on the farm with available resources, both material and human. One charcoal producer association (CPA) was interviewed to gather data on the number of charcoal producer groups, occupational injuries, illnesses and fatalities. More specifically, an inquiry was made regarding the percentage of charcoal producers doing the actual charcoal processing and the number of reported injuries, illnesses and fatalities per number of workers in relation to the amount of charcoal produced.

4.16.4 Key findings

BAGASSE BRIQUETTES

Despite the few reported injuries, the working environment in bagasse briquetting plants and tea factories has some particularities that might be worth considering during the design and formulation of occupational risk prevention plans and regulations.

Fires in bagasse storage areas are common. When bagasse is heated by the sun, gases such as methane are emitted from the natural decomposition of the biomass, creating a suitable environment for fire initiation.

Bagasse sun drying takes place in big fields on which bagasse is spread to dry. Women walk on the bagasse, turning the bagasse with their feet to accelerate the drying process (Figure 4.18). The dust concentrations are not as high as inside the briquetting factories, but women are still exposed to fine bagasse dust constantly.

Figure 4.18. Bagasse drying using open sun in Kibos, Kisumu

Photo by Natxo García López (L) and Peter Churchill Ogutu (R)

Inside briquetting plants, bagasse dust concentration in the air is very high. This is mainly due to non-existent or inefficient ventilation systems. Bagasse is often fed manually to the mills, conveyors and briquette presses. Most of the briquette factories had no dust extraction systems, and those in place are inefficient. In addition to the high bagasse dust concentrations, the workers in the bagasse briquetting plants are exposed to the inherent risks of rotary machinery, as well as to risks related to the traffic of tractors and trucks inside the poorly illuminated and ventilated buildings, which in turn leads to low visibility.

In general, personal protective equipment is not used. In some cases this is due to lack of information regarding the risks involved or of the importance of the use of this equipment, and in other cases because it is not provided by the companies. However, the most efficient way to create a safe working environment is to reduce the risk rather than to increase the protection. In the case of the bagasse dust, it is better to reduce the dust emissions and improve the ventilation systems rather than to use personal protections.

In the case of transport, both when the bagasse is transported from the sugar factory to the briquetting plant and when the briquettes are transported to the end users, the risk of traffic accidents is high. There are also risks for injuries related to loading and offloading, which is often done manually.

Regarding the briquette use in the tea factories, the workers involved in the operation and maintenance of the boiler are exposed to hot surfaces and accessories, which are potential sources of accidents. The boilers lack automatic feeding systems, so the briquettes are manually fed into the boilers, which increases the risk of accidents. Moreover, the pressurized steam generated in the boilers is an important source of potential accidents and injuries such as burns. Regarding the steam boilers, the Occupational Safety and Health Act of 2007 (GoK 2007a) describes the working environment and the safety premises that a boiler should have. In the particular case of the visited tea industries, the safety conditions in the working environment were prioritized. This is probably due to the fact that these are big and well-established companies.

CHARCOAL

The charcoal sector is organized almost entirely on informal basis. This hampers the implementation of occupational safety and health policies. However, the sector is organized in charcoal producer associations that can assume the role of implementing occupational safety and health policies and practices.

In 2008 the Government of Kenya launched Kenya Vision 2030, an initiative that aims to "transform Kenya into a newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment" (GoK 2007b). The charcoal sector is a very informal sector, and even though the sector generates a lot of money, almost none of the economic activities involved pay taxes, and thus the sector will require a severe remodeling if Vision 2030 is to be achieved.

The Government of Kenya, through the Ministry of Labour, developed the National Occupational Safety and Health Policy in 2012, which is seen as an important tool to contribute to the health and safety of employees in the workplace.

In the charcoal sector, injuries are common although they are often not reported to relevant offices. Such injuries are due to trees falling on people and injuries during loading and unloading, which are common during harvesting and movement of wood resources. People are also exposed to dangers of snake bites; exposure to smoke, dust and particulate matter during production and handling of charcoal, which contributes to increased cases of respiratory diseases. Burns are also common during harvesting of charcoal, especially when kilns are dismounted when the charcoal is still hot.

Figure 4.19. A group of charcoal producers supervising a traditional kiln in operation

Photo by Natxo García López

4.16.5 Conclusions and recommendations

Synthesis of findings

Companies and organizations seem to have difficulties in sharing their experience regarding occupational safety and health and whether the Occupational Safety and Health Act regulations are implemented. In most of the briquette production factories visited, even though cases of injuries had been reported, no records or data were available for sharing.

Charcoal is a very informal sector, and although injuries, illness and fatalities related to charcoal production, transport and commercialization do occur, data were lacking. Having a functional and transparent occupational safety and health policy would contribute to a better working environment.

Practices and policies to improve sustainability

Information campaigns about the importance of functional and transparent occupational safety and health policies would contribute to a better and safer working environment.

Charcoal producer groups could lead the implementation of occupational safety and health policies and practices within the charcoal production sector.

Future monitoring

Further studies aimed at assessing the status of injuries, illness and fatalities in the entire bioenergy sector in Kenya would be a valuable intervention that could help the development of the sector. Considering the enormous challenges that the charcoal sector might face when the government decides to implement a comprehensive transformation of the sector, reliable data on injuries, illness and fatalities could be a good resource for the different government agencies involved in that process.

4.16.6 References

Government of Kenya (2007a). *The Occupational Safety and Health Act*, 2007. Nairobi.

Government of Kenya (2007b). *Kenya Vision 2030. The Popular Version*. Nairobi.

Government of Kenya (2012). *The National Occupational Safety and Health Policy, 2012*. Nairobi.

International Labour Organization (2019). ILOSTAT. https://www.ilo.org/ilostat/faces/oracle/webcenter/portalapp/pagehierarchy/Page21.jspx. Accessed 12 May 2019.

4.17 Indicator 17. Productivity

4.17.1 Definition

(17.1) Productivity of bioenergy feedstocks by feedstock or by farm/plantation
(17.2) Processing efficiencies by technology and feedstock
(17.3) Amount of bioenergy end product by mass, volume or energy content per hectare per year
(17.4) Production cost per unit of bioenergy

4.17.2 Measurement unit(s)

(17.1) Tons/ha per year;
(17.2) MJ/ton;
(17.3) Tons/ha per year, m^3/ha per year or MJ/ha per year;
(17.4) US dollars/MJ

4.17.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

This indicator focuses on the productivity of sugarcane bagasse briquettes.

- For the productivity of sugarcane feedstocks by feedstock or by farm/plantation (17.1), the measurement unit is tons/ha per year
- For processing efficiencies by technology and feedstock (17.2), the measurement unit is MJ/ton.
- For the amount of sugarcane bagasse by mass, volume or energy content per hectare per year (17.3), the measurement unit is tons/ha per year, m^3/ha per year or MJ/ha per year.
- For the production cost per unit of sugarcane bagasse briquettes (17.4), the measurement unit is $/MJ.

CHARCOAL

The indicator focuses on the productivity of the land used to produce charcoal, as well as on the overall economic efficiency of the production, which to an extent will capture the overall efficiency of use of all inputs. The assessment of this indicator will be drawn from both primary and secondary data sources available. It will focus mainly on the productivity of the acacia species for charcoal production and compare the traditional earth kiln to the improved earth kiln.

Sub-indicator 17.3 is related to forest yield. Yield is the quantity of wood that can be sustainably removed from a given forest over a period of time without affecting the production capacity of the growing stock in future periods. Yields are expressed in m^3/ha/year and vary from one forest type to the other depending on species composition, stocking and management objective.

4.17.4 Key findings

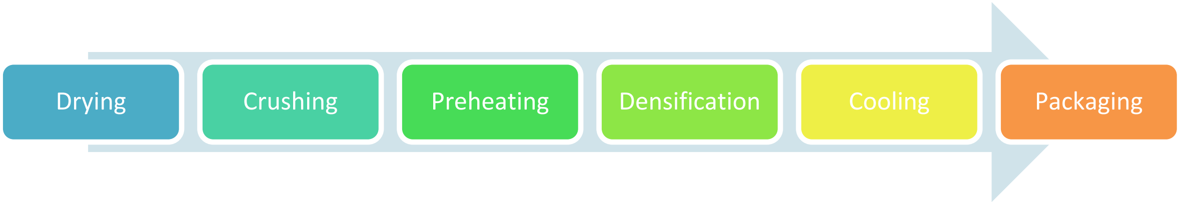
BAGASSE BRIQUETTES

According to the Sugar Directorate, around 60 per cent of the bagasse generated is used internally by sugar mills for their boiler operations, while 40 per cent remains unutilized and is instead deposited in open fields. Over 1.7 million tons of sugarcane bagasse was produced by all 11 sugar factories in Kenya in 2017. Of this production, around 510,000 tons remained unutilized and was available for briquette production and other products (AFA-SD 2017).

One ton of crushed sugar cane produces 0.3590 to 0.3968 tons of bagasse, which normally has a moisture content of between 12 per cent and 14 per cent (AFA-SD 2018). This translates to a consistent 9-10 per cent moisture in the final product, which is recommended by the Kenya Briquette Manufacturers Association (KCIC, n.d.).

The briquette companies produce 170 to 1,200 tons of briquettes per month depending on the weather and the availability of raw materials.

Since the pathway focuses on non-carbonized briquettes, the briquette production per ton of bagasse is a ratio of 1:1 since there are no significant weight losses from processing. It mainly goes through the highlighted process below:



Once the briquettes are produced, the useful energy yield from bagasse briquettes delivered to industries is around 18,000 MJ/ton with an ash content of 10-30 per cent. Non-carbonized briquettes are generally too smoky to be consumed in commercial or residential settings and are only really suitable for industrial wood furnaces.

The cost of a ton of briquette varies widely depending on the intended market but generally ranges between $0.01673 and $0.0239 per MJ.

CHARCOAL

Acacia species are the most used trees for charcoal production in Kenya (Mutimba and Barasa 2005). This is attributed to the species' availability, especially in rangelands, and the production of high-quality charcoal. The most widely used and preferred species are *Acacia tortilis, A. nilotica, A senegal, A. mellifera, A. polyacantha, A. drepanolobium, A. mearnsii and A. Xanthophloea*. Notably, the different species have different productivity rates, as shown (as examples) in Table 4.41.

Table 4.41. Yield per year of *A. drepanolobium* and *A. mearnsii* when using a low-efficiency kiln

Acacia species	Yield per year (tons/ha) (low-efficiency kiln used)
A. drepanolobium	0.18
A. mearnsii	1.01

Source: Mugo et al. 2007.

The three most common methods of charcoal production are earth kilns, masonry kilns and metal kilns.

- Earth kilns are of various types but the most common are the traditional earth kiln, improved earth kiln and Casamance kiln.
- Masonry kilns are usually of the beehive and half orange type; they are recommended for charcoal conversion in areas where fuelwood is available for prolonged periods, such as in large-scale land clearing or in fuelwood plantations.
- Metal kilns include the drum kiln, meko kiln and Mark V type.

The majority of charcoal producers (99 per cent) use traditional earth kilns, which have very low recovery rates, estimated at 16 per cent according to MEWNR (2013a) but that can be as low as 10 per cent (SalvaTerra 2014).

To calculate the energy loss during conversion, the average conversion ratio considered was 10:1 which means that 10 kilograms of wood is burned to produce 1 kilogram of charcoal.

Wood has an energy content of 15 MJ/kg and charcoal has an energy content of 28 MJ/kg (Foley 1986). Therefore, the net energy losses to produce one kilogram of charcoal, assuming a conversion rate of 10 per cent, are: 150 MJ (10 kg wood) - 28 MJ (1 kg charcoal) = 122 MJ/kg of charcoal, which is equivalent to 12,200 MJ/tons charcoal.

In calculating the production cost, the following was applied: 1 bag of 35 kg = 35 × 28 = 980 MJ. It costs $1.59. Therefore, 1 MJ of charcoal = 1.59/980 = 0.00116 $/MJ

4.17.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

The amount of bagasse produced by all the sugar factories in Kenya is enormous but remain underutilized. Densification of the bagasse is beneficial for the environment as it helps solve the residual disposal problem and at the same time provides a useful source of renewable energy.

As mentioned in Indicator 18, currently the prices of fuelwood seem to be cheaper than bagasse. This is due to the high production and transport costs. In an ideal situation, agricultural wastes should be cheaper than using fuelwood since bagasse briquettes and pellets have a high calorific value, low ash content, low moisture content and are classified as carbon neutral by the United Nations Framework Convention on Climate Change. In general, alternative fuels are transported over much longer distances and are more expensive compared to fuelwood in terms of net heat content.

Practices and policies to improve sustainability

To realize the full potential use of agricultural residues by the tea industry, government should create an enabling environment for establishing briquetting companies through incentives such as tax exemptions on briquetting equipment, creating awareness, enforcing stringent laws on logging and easier business formalisation procedures.

More trainings on briquette production should be offered by the Ministry of Energy.

Future monitoring

Information on bagasse briquette production costs is not readily available. The processing technologies used to briquette bagasse have also not been documented; therefore, it is difficult to know the processing efficiencies. Considerable research still needs to be done on the efficiency of bagasse production technologies used by the various companies.

CHARCOAL

Synthesis of the findings

Replanting of trees cut down for charcoal, use of mature stems leaving others to grow from the same tree and choosing tree species that coppice well and those that naturally regenerate is important for sustainability in charcoal production. It is equally critical to recommend suitable species in different agroclimate conditions. For example, the studied *A. mearnsii* grows well in agroclimate zones I-III (Maundu and Tengnas 2005). It is suitable for woodlots but should not be intercropped, as it competes for nutrients, and should be well managed, as it is potentially a weed. It is also important to ensure that the tree species recommended do well in naturally dry conditions, such as *A. tortilis* for agroclimate zones IV-VII (Maundu and Tengnas 2005).

The majority of charcoal producers (99 per cent) in Kenya still use traditional earth kilns to carbonize wood. These kilns have an efficiency of around 10 per cent, which means that a vast area of forests is required to provide for annual demand for charcoal.

The identification of viable efficiency options for the charcoal sector is urgently needed, as the combination of unsustainable harvesting of trees for charcoal production, increased charcoal consumption and the use of inefficient traditional kilns forms a key threat to forest resources in Kenya.

If the conversion loss is minimized through the application of efficient methods, fewer trees would be required to produce the same volume of charcoal.

Awareness needs to be created among the charcoal producers on the importance of using efficient kilns, which have higher efficiency levels from 35 per cent. This will lower the rate of harvesting of forests to meet energy demand.

Practices and policies to improve sustainability

Charcoal production has for a long time been done unsustainably with illegal dealers clearing thousands of mature indigenous trees. Destruction of forests in Kenya has negatively affected the ecosystem, leading to protracted droughts causing extreme food insecurity and malnutrition.

In order for charcoal production to become sustainable, the following need to be implemented:

- Charcoal legislation is not properly coordinated in Kenya. This makes charcoal extraction very unsustainable. In this regard, legislation needs to be harmonized to streamline the sector.
- Increased efficiency in charcoal production can reduce the pressure on forests: instead of using 10 kilograms of wood to produce 1 kilogram of charcoal, improved technologies can cut the use of wood down to 3 kilograms to 6 kilograms according to the technology used and best practices applied. This can be done by promoting the use of efficient kilns.
- For Kenya to achieve its 2030 vision of increasing the forest cover to 10 per cent, afforestation and reforestation as well as improving plantation management by appropriate silvicultural practices such as thinning, pruning and extension of rotation age can reduce forest carbon emissions in both public and private plantations.
- It is crucial to replant trees cut down for charcoal or to select tree species that regenerate naturally and/or that coppice well, to ensure the presence of biomass for uptake of carbon dioxide, hence maintaining the neutral impact of biomass energy on global warming potential (GWP).

Future monitoring

There are no conclusive data and information on the production cost per unit of charcoal because the available figures seem to be too low compared to its annual retail value as estimated by various studies. This might be because the charcoal producers fear disclosing the amount they make from charcoal production to avoid regulation. There is a need to do further research.

4.17.6 References

Agriculture and Food Authority, Sugar Directorate (2017). *Sugar Year Book.* Ministry of Agriculture and Industry. Nairobi.

Agriculture and Food Authority, Sugar Directorate (2018). *Survey of Briquette Production Using Sugarcane Bagasse in the Sugar belt Regions of 2018.* MAI, Nairobi, Kenya.

Foley, G. (1986), *Charcoal Making in Developing Countries*. Technical Report No. 5. International Institute for Environment and Development. London.

Kenya Climate Innovation Center (n.d.). http://www.kenyacic.org/news/sugarcane-bagasse

Kenya Forestry Research Institute (2014).*Reafforestationand water conservation in drylands*. Guidelines for students and researchers.

Maundu and Tengnas (2005). *Useful trees and shrubs for Kenya*,ICRAF-ECA

Ministry of Environment, Water and Natural Resources (2013a). *Analysis of the Charcoal Value Chain in Kenya*. Nairobi. http://www.kenyaforestservice.org/documents/redd/Charcoal%20Value%20Chain%20Analysis.pdf.

Mugo, F., Nungo, R., Odongo, F., Chavangi, N. and Abaru, M. (2007). *An Assessment of the Energy Saving Potential and Heat Loss Pattern in Fireless Cooking for Selected Commonly Foods in Kenya.* CARPA Working Paper Series No. 2.

Mutimba, S. and Barasa, M. (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainable Charcoal Industry in Kenya.* Energy for Sustainable Development Africa. Nairobi.

Salva Terra (2014).*Production and marketing of sustainable charcoal made from forest plantation in the periphery of Kinshasa*,DR Congo,GIZ

4.18 Indicator 18. Net energy balance

4.18.1 Definition

Energy ratio of the bioenergy value chain with comparison with other energy sources, including energy ratios of: (18.1) feedstock production; (18.2) processing of feedstock into bioenergy; (18.3) bioenergy use; and/or (18.4) life cycle analysis.

4.18.2 Measurement unit(S)

Ratios

4.18.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

- Research on this indicator involved both desktop research and a field visit.
- Desktop research was used to ascertain conversion factors such as kWh to MJ and litres to MJ.

CHARCOAL

- Data on this indicator involved literature review of past charcoal studies.
- A field visit to Kitui and Narok

4.18.4 Key findings

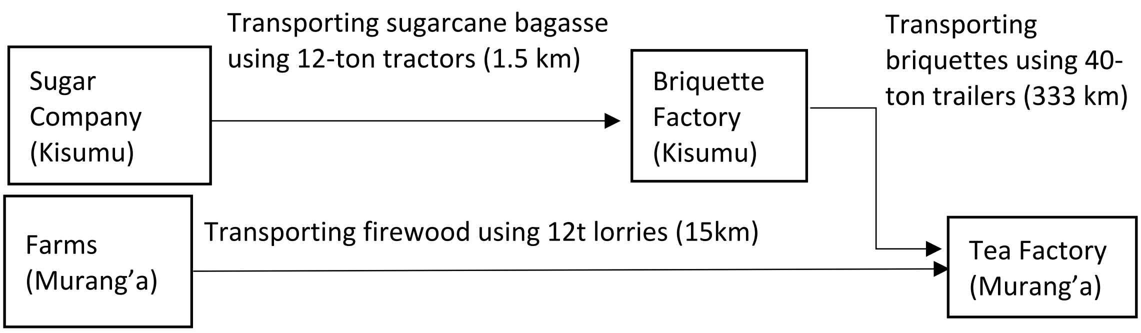
BAGASSE BRIQUETTES

As per conducted field visits, the case study tea factory used 21,382 m^3 (11,760 tons using 550 kg/m^3) of fuelwood. This is equivalent to 177,577 GJ (at 15.1 GJ per ton). Assuming that briquettes produce 18.3 GJ per ton (García López 2016), the same amount of energy, 177,577 GJ, can be produced by 9,704 tons of briquettes. This information can be summarized as in Table 4.42. During the field visits, transport of bagasse and fuelwood was found to be as in Figure 4.20.

Table 4.42. Tons of fuelwood and bagasse needed to produce energy needed by factory in 100 per cent bagasse and 100 per cent fuelwood scenarios

Type of fuelwood	Tons	Total GJ
Bagasse	9 704	177 577
Fuelwood	11 760	177 577

Figure 4.20. Stages studied in use of sugarcane bagasse briquettes and fuelwood in tea factories
(image from Indicator 4)



The following scenarios were created to help visualize the energy consumed during transport of bagasse, briquettes and fuelwood. It is assumed that bagasse to briquette conversion is 1:1 hence there is no waste during this process. As per Figure 4.20, 12-ton and 40-ton trucks are used at different stages as per the findings from field visits. The 40-ton truck is assumed to travel 3 kilometres per litre of fuel while a 12-ton truck is assumed to travel 6 kilometres per litre of fuel, where 1 litre = 37.3 MJ. A 40-ton truck was introduced in the fuelwood scenario in order to analyse the impact of increasing truck carrying capacity on energy consumed during transport.

Table 4.43 provides the results for the three scenarios: 100 per cent briquette use and 100 per cent fuelwood use under the current transport scenario, and 100 per cent fuelwood use with increased truck carrying capacity. The bagasse briquette use scenario in the table is ideal. Bagasse briquettes are transported 333 kilometres, whereas fuelwood is transported 15 kilometres. In cases where fuelwood is transported over long distances and bagasse is transported with a 40-ton truck, the briquettes pathway will consume significantly less energy.

Table 4.43. Theoretical scenario at 100 per cent briquette use

Transport of:	Scenario (use)	Truck tonnage	Total no. of tons	No. of trips	Distance travelled per trip in km	Total distance travelled in km	Litres of fuel used	Total MJ	Total energy per scenario
Bagasse	100% bagasse	12	9 704	809	1.50	1 213	202	7 541	1 011 945
Briquette		40	9 704	243	333	80 783	26 928	1 004 405	
Fuelwood	100% fuelwood	12	11 760	980	15	14 700	2 450	91 386	91 385
Fuelwood	100% fuelwood	40	11 760	294	15	4 410	1 470	54 831	54 831

Most factories use around 5-10 per cent bagasse briquettes (SERC 2017), whose energy consumption during transport would be as shown in the scenario in Table 4.44.

Table 4.44. A 5 per cent bagasse briquette use scenario

Transport of:	Scenario (use)	Truck tonnage	Total no. of tons	No. of trips	Distance travelled per trip in km	Total distance travelled in km	Litres of fuel used	Total MJ	Total energy per scenario
Bagasse	5% bagasse, 95% fuelwood	12	1 940	2	1.50	3.7	0.61	23	Included below
Briquette		40	1 940	1	333	245	81.60	3 044	
Fuelwood		12	11 172	931	15	13 965	2 327.52	86 816	89 883
Fuelwood		40	11 172	279	15	4 190	1 396.51	52 090	55 156

Factories can increase their bagasse briquette consumption to 20%. This scenario is shown in Table 4.45.

Table 4.45. A 20 per cent bagasse briquette use scenario

Transport of:	Scenario (use)	Truck tonnage	Total no. of tons	No. of trips	Distance travelled per trip in km	Total distance travelled in km	Litres of fuel used	Total MJ	Total energy per scenario
Bagasse	20% bagasse, 80% fuelwood	12	1 940	162	1.5	242	40	1 508	Included below
Briquette		40	1 940	49	33	16 156	5 385	200 880	
Fuelwood		12	9 408	784	15	11 760	1 960	73 108	275 497
Fuelwood		40	9 408	235	15	3 528	1 176	43 865	246 254

Energy is also consumed during processing of briquettes, where 50 kWh is used to process 1 ton of briquettes as per data from field visits. Calculations of energy consumption for the 100 per cent, 20 per cent and 5 per cent scenarios described above are provided in Table 4.46.

Table 4.46. Energy consumption for scenarios of 100 per cent, 20 per cent and 5 per cent briquette use

Processing of:	Scenario	kWh/Ton	Tons	Total kWh	MJ
Briquettes	100%	50	588	29 405	105 858
	20%	50	118	5 881	21 172
	5%	50	29	1 470	5 293

Energy consumed during processing of fuelwood was calculated under the assumption that 1 litre of fuel will be consumed for 1 ton of fuelwood. The 100 per cent, 95 per cent and 80 per cent scenarios are as presented in Table 4.47.

Table 4.47. Energy consumed during processing of 1 ton of fuelwood at 100 per cent, 95 per cent and 80 per cent

Processing of:	Scenario	MJ/ton	Tons	MJ
Fuelwood	100%	37.30	11 760	438 652
	95%	37.30	11 172	416 719
	80%	37.30	9 408	350 921

Total energy processing scenarios are as presented in Table 4.48.

Table 4.48. Total energy for fuelwood and briquette mixes

Fuelwood scenario	Briquette scenario	Energy used: Transport and processing
0%	100%	1 746 664
100%	0%	438 652
95%	5%	422 012
80%	20%	372 093

Referencing energy produced in Table 4.42 and comparing it to the energy consumed during transport, net energy is as presented in Table 4.49.

Table 4.49. Net energy available using various ratios of briquette to fuelwood

Lorry Size	Scenario	Energy used (MJ) in processing + transport	Energy produced (MJ)	Net energy (MJ)
-	100% briquette	2 758 609	177 577 510	174 818 900
12 ton	80% fuelwood	975 751	177 577 510	176 601 758
12 ton	95% fuelwood	641 466	177 577 510	176 936 043
12 ton	100% fuelwood	530 037	177 577 510	177 047 472
40 ton	80% fuelwood	946 508	177 577 510	176 631 001
40 ton	95% fuelwood	606 739	177 577 510	176 970 770
40 ton	100% fuelwood	493 483	177 577 510	177 084 026

The 100 per cent fuelwood scenario has the largest net energy, which is reduced as briquettes increase. Using 40-ton trucks to transport fuelwood also reduces the energy consumed for the same scenarios.

CHARCOAL

As per conducted field visits in Kitui and Narok, the distances were determined to be 175 kilometres and 141 kilometres respectively. Two trucks of 12 and 40 tons were used in this analysis in order to analyse the impact of increasing carrying capacity. The 40-ton truck is assumed to travel 3 kilometres per litre of fuel while a 12-ton truck is assumed to travel 6 kilometres per litre of fuel, where 1 litre = 37.3 MJ. The average bags of charcoal during peak season is 25,000 bags of charcoal where 1 bag represents 0.045 tons, totaling 1,125 tons.

It was assumed that after felling, the fuelwood was not transported to the point of carbonization hence no distance was travelled and thus no energy was consumed to transport the wood to be carbonized. Note that these calculations have been done one-way due to a lack of information regarding what the trucks carry on their collection run. The amount of energy consumed during transport is shown in Table 4.50.

Table 4.50. Transport of charcoal from Kitui and Narok to their nearest markets

Scenario	Truck tonnage	Total no. of tons	Distance travelled in km	Total distance travelled in km	litres (if 1 L = 6 km)	Total MJ (1 L = 37.3 MJ)
Kitui	12	1 125.00	175.00	16 406.25	2 734.38	101 992.19
Narok	12	1 125.00	141.00	13 218.75	2 203.13	82 176.56
Kitui	40	1 125.00	175	4 921.88	820.31	30 597.66
Narok	40	1 125.00	141	3 965.63	660.94	24 652.97

The energy consumption of traditional and improved kilns was analysed as shown in Table 4.51, and an ideal kiln was added for use as a baseline for comparison of the two kilns. The ideal kiln was assumed to consume 0.1 per cent of fuelwood for charcoal production.

Table 4.51. Energy consumed during processing of wood fuel

Kiln type	Efficiency	Tons of charcoal	Amount of fuelwood per ton	Amount of fuelwood consumed	Total energy per ton of fuelwood	Energy consumed during processing	Total energy consumed
Traditional	15%	1,125	7 500	6 375	96 262 500	279 750	96 542 250
Improved	30%	1,125	3 750	2 625	9 843 750	139 875	9 983 625
Ideal Kiln	100%	1,125	1 125	112.50	126 562.50	41 962.50	168 525

Source: SERC 2019

The energy production of the Kenya Ceramic Jiko stove and the traditional Jiko stove while using charcoal was analysed as shown in Table 4.52, and an ideal Jiko stove was added for use as a baseline for comparison of the two Jikos.

Table 4.52. Energy produced during use of charcoal

Jiko type	Efficiency	Charcoal for use	Charcoal used in tons	Energy output in MJ
Traditional	15%	1 125	168.75	4 893 750
Kenya Ceramic	33%	1 125	371.25	10 766 250
Ideal	100%	1 125	1 125	32 625 000

Source: SERC 2019

Kitui County was used to calculate net energy since the county had a higher amount of fuel consumption during transport as shown in Table 4.50; thus net energy for Narok will be higher. Net energy while using a 12-ton truck is as shown in Table 4.53.

Table 4.53. 12-ton truck net energy

Kiln type	Energy consumed during production	Energy consumed in transport (Kitui)	Jiko type	Energy produced	Net energy
Traditional	96 542 250	101 992.19	Traditional	4 893 750	(91 750 492.19)
Improved	9 983 625	101 992.19	Kenya Ceramic	10 766 250	680 632.81
Ideal	168 525	101 992.19	Ideal	32 625 000	32 354 482.81

As shown above, the improved kiln is more efficient than the traditional kiln although further improvements are needed since, in comparison to the ideal scenario, a lot of energy is still lost during production. Net energy while using a 40-ton truck is as shown in Table 4.54.

Table 4.54. 40-ton truck net energy

Kiln type	Energy consumed during production	Energy consumed in transport (Kitui)	Jiko type	Energy produced	Net energy
Traditional	96 542 250	61 195.31	Traditional	4 893 750	(91 709 695.31)
Improved	9 983 625	61 195.31	Kenya Ceramic	10 766 250	721 429.69
Ideal	168 525	61 195.31	Ideal	32 625 000	32 395 279.69

As shown, the Kenya Ceramic Jiko stove is more efficient than the traditional Jiko stove although further improvements are needed since, in comparison to the ideal scenario, a lot of energy is still lost during production. Of note is that an increase in carrying capacity, from 12 tons to 40 tons, leads to an increase in net energy.

4.18.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

Increasing bagasse consumption increases the total amount of energy consumed for transport, which increases net energy.

The use of a 40-ton truck instead of a 12-ton truck can also reduce energy consumption during transport, which increases the net energy.

Practices and policies to improve sustainability

The briquette industry needs to be organized in a way that it is able to present its solutions to Kenya Private Sector Alliance, Kenya Association of Manufacturers, Kenya Tea Development Agency and Kenya Coffee Board, among other umbrella organizations whose buy-in would be fundamental for the entry of the briquette industry to various markets (KCIC n.d.).

Existing boilers should be improved technically to improve compatibility with briquettes, as most are either furnaces or customized for fuelwood use.

Awareness creation should be done for tea factories on the financial viability of using alternative bioenergy sources such as bagasse briquettes.

Tea factories should automate the feeding of boilers to increase energy efficiency at the boiler section by reducing the period and number of times that the boiler door is opened.

Future monitoring

Challenges faced in the analysis of this indicator were a lack of definitive data on the energy consumption of 40-ton and 12-ton trucks and on energy use during the processing of both briquettes and fuelwood. The figures used were based on factory self-reporting through field visits.

The GBEP indicators should strive to accommodate solid biomass, which is more prevalent in sub-Saharan African countries.

CHARCOAL

Synthesis of the findings

Most charcoal consumed is produced using simple technologies with low efficiency, resulting in substantial losses of wood and energy (FAO 2017).

Sensitization and awareness creation should be performed to encourage charcoal producers to use more-efficient technologies to avoid large losses and reduce deforestation, as well as to encourage charcoal users to reduce the amount of charcoal used and increase the amount of energy derived per unit of charcoal burned.

Practices and policies to improve sustainability

The community should be sensitized on the use of efficient kilns and improved cookstoves (Mathai and Neuberger 2015).

Reducing the massive wastage during carbonization will go a long way in reducing deforestation. This can be achieved by partnering with research organizations like Kenya Forestry Research Institute to ensure the development of cheaper and user-friendly wood carbonization technologies.

The community should be educated on how to make charcoal briquettes. During the production, transport, wholesaling and retailing of the charcoal, a significant proportion of it ends up as waste in the form of dust. Cumulatively this totals to tons of charcoal ending up as waste daily. This waste could potentially be turned into briquettes and reduce the demand for lump wood charcoal.

Future monitoring

Data are needed where assumptions are indicated to have been made in this report.

4.18.6 References

FAO (2017). The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods, by J. van Dam. Rome, Food and Agriculture Organization.

García López, N. (2016). *Biomass Utilization for Energy Purposes in Kenya: Fuel Charactersitics and Thermochemical Properties.* BSc thesis, Umeå University, Sweden.

KCIC (n.d.). *Briquette Sector in Kenya.* https://kenyacic.org/sites/default/files/publications/BRIQUETTES%20SECTOR.pdf.

Neuberger, I. (2015). *Policy Solutions for Sustainable Charcoal in Sub Saharan Africa*. World Future Council. Hamburg.

Strathmore Energy Research Centre (2017). *Bioenergy Analysis for the Tea Industry in Kenya.* Nairobi.

Strathmore Energy Research Centre (2019). Excel calculation. Nairobi.

Mathai, W., and Neuberger, I. (2015). Policy Solutions for Sustainable Charcoal in Sub-Saharan Africa, Hamburg, Germany: World Future Council.

4.19 Indicator 19. Gross value added

4.19.1 Definition

Gross value added per unit of bioenergy produced and as a percentage of gross domestic product.

4.19.2 Measurement unit(s)

$/kg and $/MJ

4.19.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

For bagasse briquettes, research on this indicator involved both desktop research and a field visit. This decision was made in order to get first-hand information / data from both producers and users and to encourage the use of bagasse as an alternative fuel where available and own consumption of fuelwood through plantations (GBEP 2019).

CHARCOAL

For charcoal, data collection involved both literature review of past charcoal studies and a field visit to Kitui and Narok. However, the report’s data is more skewed towards the national outlook and Narok County due to the availability of data on the two. The numbers provided are not gross value

added but they provide an overview of the contribution of the charcoal sector to the Kenyan economy.

4.19.4 Key findings

BAGASSE BRIQUETTES

As per conducted field visits, the average cost per kilogram of fuelwood is KSh 4,181/ton and of bagasse is KSh 9,666/ton. The case study tea factory used 21,382 m^3 (11,760.1 tons using 550 kg/m^3) of fuelwood; 11,760.1 tons of fuelwood produces 177,577.51 MJ (at 15.1 MJ per ton). Using a bagasse-to-fuelwood energy ratio of 20:1, the same amount of energy would be produced by 588.01 tons of bagasse. This information above can be summarized as shown in Table 4.55.

Table 4.55. 100 per cent bagasse and 100 per cent fuelwood scenarios

Type	Cost per ton	No. of tons	Total cost in KSh
Bagasse	9 666	9 704	93 795 859
Fuelwood	4 181	11 760.1	49 168 978.10

Source: GBEP 2019

Assuming a production of 200 m^3/ha as per Oballa et al. (2010), the cost of producing 1 m^3 of eucalyptus is KSh 519.5/m^3 (KSh 944.5/ton). From the field visits, for factories near plantations, other costs such as transport, loading, offloading, drying and labour costs are around KSh 2,500/ton. Adding this information to the table above:

Table 4.56. 100 per cent plantation fuelwood scenario

Type	Cost per ton	No. of tons	Total cost in KSh
Plantation fuelwood	3 445	11 760	40 507 664

The above scenarios are ideal scenarios. Most factories use a maximum of 10 per cent bagasse, and plantations take 5 to 8 years to mature. With proper planning, the factory can supplement 10 per cent of its fuelwood use per year by harvesting 10 hectares of land yearly. To achieve this, the trees would have to be planted on rotation for harvesting for 5-8 years hence 50-80 hectares of land is required. The scenario described would provide the following savings in comparison to 100 per cent bought fuelwood:

Table 4.57. 10 per cent bagasse, 10 per cent plantation fuelwood and 80 per cent bought fuelwood scenarios

Type	Cost per ton	No. of tons	Total cost in KSh
Bagasse at 10%	9 666	970	568 361
Plantation fuelwood at 10%	3 444.5	1 176.01	4 050 766
Bought fuelwood at 80%	4 181	9 408.08	39 335 182
Total			43 954 310

With mechanized feeding of boilers, bagasse use can be increased to above 20 per cent, and the scenario is as follows:

Table 4.58. 20 per cent bagasse and 80 per cent bought fuelwood scenarios

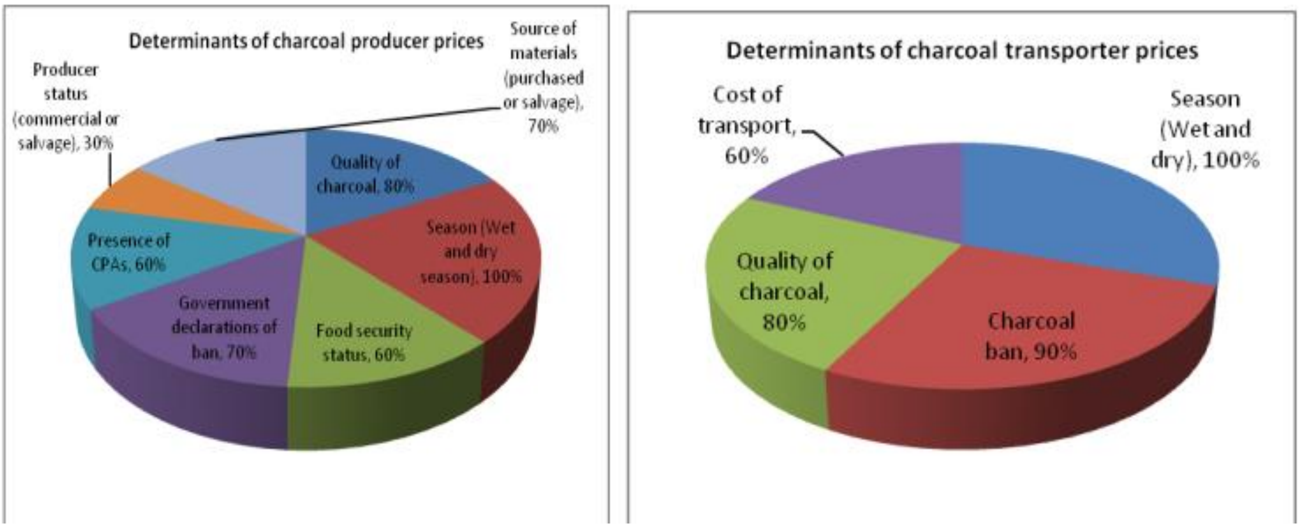
Type	Cost per ton	No. of tons	Total cost in KSh
Bagasse at 20%	9 666	117.6	1 136 721.6
Bought fuelwood at 80%	4 181	9 408.08	39 335 182.48
Total			40 471 904.08

CHARCOAL

At the national level, according to the Ministry of Environment, Water and Natural Resources (2013) the factors affecting charcoal pricing in Kenya are:

- **Technical factors:** These hinge on the quality of charcoal determined by technology used, tree species and presence of debris (presence or absence of dust, soil particles, un-burned wood and twigs).
- **Economic factors:** Most producers engage in charcoal production as a strategy to survive prolonged droughts. For families lacking alternative livelihoods there is a high risk of poverty and hunger especially since charcoal prices tend to be lowest during food insecurity seasons.
- **Supply and demand:** Major towns offer better prices compared to smaller markets. This is due to the high concentration of demand in major markets.
- **Climate factors:** Prices tend to be higher during the rainy season than the dry season due to a reduction of supply. This is because during the wet season:
    - In charcoal processing, carbonization takes longer due to high moisture content of both wood and soil thus increasing charcoal production costs;
    - Most roads are impassable making market deliveries difficult which has an effect on prices;
    - Most charcoal producers turn to farming activities as most of them are subsistence farmers,
- **Policy and institutional factors:** Temporary bans by the national and county governments, taxes that vary from one town to the other and weak charcoal producer associations (CPAs) and charcoal producer groups (CPGs) are some of the factors that affect charcoal pricing.
- **Corruption and illegal taxes:** Rampant corruption exists, especially along the highways by police officers. The payment of illegal taxes on the roads was found to contribute to up to 15 per cent of the cost of each bag of charcoal.

Figure 4.21. Determinants of charcoal pricing



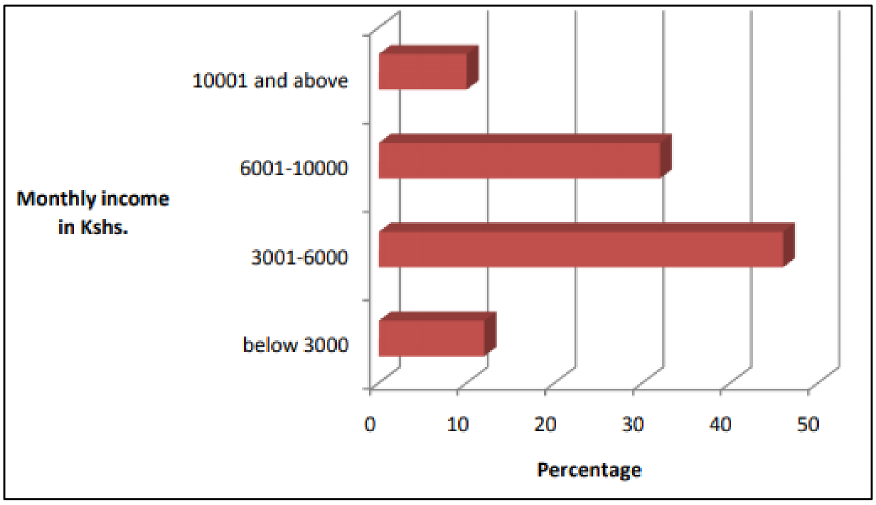
Source: MEWNR 2013

Other findings were:

- **Employment:** More than 200,000 people were directly employed in charcoal production and an estimated 500,000 others were involved in transport and vending of charcoal, who were in turn believed to be supporting over 2.5 million dependants (Mutimba and Barasa 2005).
- **Income:** Survey data from the national study further break down the average incomes generated from charcoal as KSh 4,496 for producers, KSh 11,298 for transporters and KSh 7,503 for vendors (Tesot 2014); thus vendors and transporters get the lion's share of the income generated in the charcoal sector.
- **Business:** Producing cookstoves provides good business opportunities for producers and vendors suggesting that an average of 337 improved cookstoves per month are produced per producer, earning them an average monthly income of $120 to $240 (Tesot 2014), which is distributed within the cookstove value chain.

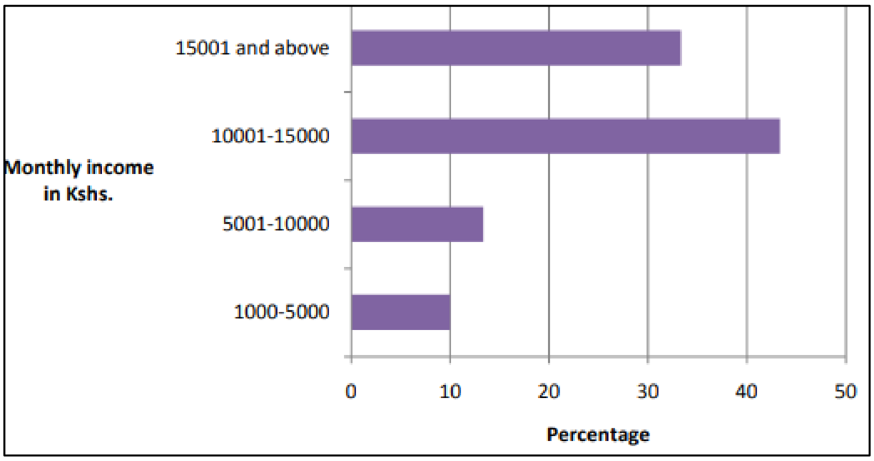
At the Narok County level, Figures 4.22 to 4.26 show some advantages / value that charcoal has contributed to the Narok County economy:

Figure 4.22. Charcoal producers' monthly income



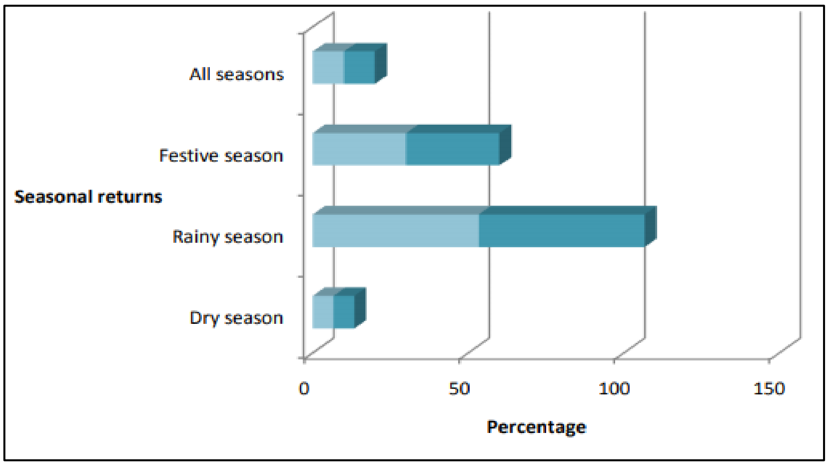
Source: Tesot 2014

Figure 4.23. Charcoal merchants' monthly income



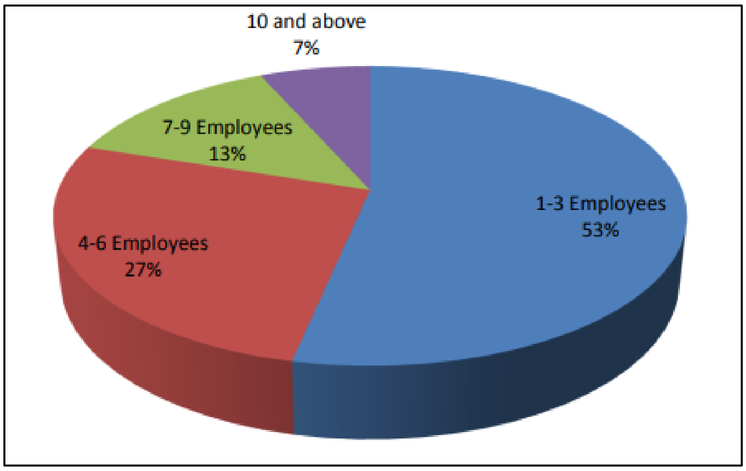
Source: Tesot 2014

Figure 4.24. Seasonal charcoal business returns



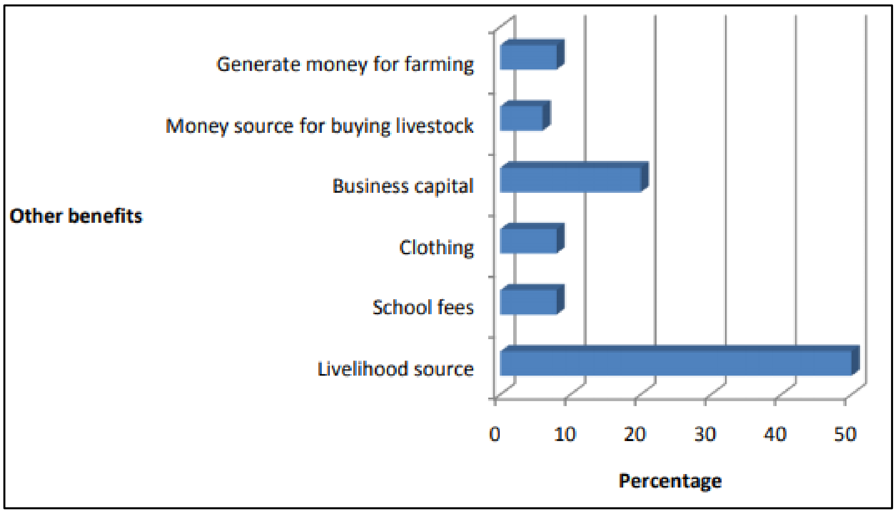
Source: Tesot 2014

Figure 4.25. Charcoal business employment rate



Source: Tesot 2014

Figure 4.26. Benefits associated with charcoal enterprise in Narok-South Sub-County



Source: Tesot 2014

4.19.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

Increasing bagasse use and plantation fuelwood use saves costs.

Bagasse briquette quality is important since the energy density of briquettes determines the briquette-to-fuelwood ratio.

Practices and policies to improve sustainability

Farmers should be encouraged to own plantations in order to increase the availability of fuelwood and encourage sustainability in the tea sector.

Incentives should be provided for factories to establish their own plantations for fuelwood.

Tax incentives should be provided for briquette bagasse producers to set up factories and improve the quality of their products.

Future monitoring

Challenges faced regarding the analysis done in this indicator included the varying costs of briquetting and varying information from different factories, hence the need to pick one factory.

Standard distances were assumed even though different factories had different travel distances. It is important that future monitoring comes up with models that simplify calculations and consider different factory distances.

The GBEP indicators should work to accommodate solid biomass, which is more prevalent in sub Saharan African countries.

CHARCOAL

Synthesis of the findings

Training on charcoal handling and briquetting is required to improve on recovery rates and reduce breakages and to make use of the charcoal dust produced.

There is a need for alternative livelihoods and initiation of microfinance schemes where the producers can get upfront loans and/or payments to cushion them. This would make them more resilient and able to wait for better prices.

Practices and policies to improve sustainability

Unaccounted-for charcoal imports and exports make it difficult to determine the true value of the charcoal industry to the Kenyan economy and ultimately complicate the planning process for proper management of the sector. There is a need for a study to determine the extent of charcoal movement in and out of the country.

Strong charcoal producer associations (CPAs) and charcoal producer groups (CPGs) that operate within the law will help to regulate both logging for fuelwood and market prices. County governments should work in cooperation with these charcoal producer associations.

Under the current laws, the only revenue from charcoal that goes either to the central or county governments is the KSh 20 per bag levied as licensing and/or access fees. If the sector is well-regulated, a structured system could be developed for enhanced revenue collection.

To ensure that consumers are protected and therefore motivated to participate in sustainable practices, there is a need to widen the scope of consumer protection laws, for example by standardizing the quantities in which charcoal is sold and introducing quality standards for charcoal and charcoal briquettes.

Future monitoring

The major challenge in this pathway indicator was the availability of adequate data following the 2018 charcoal ban. The impact of the charcoal ban needs to be evaluated the next time this study is undertaken.

4.19.6 References

Global Bioenergy Partnership (2019). *Global Bioenergy Partnership Indicators for Kenya.* Global Bioenergy Partnership Project Partners. Kisumu.

Ministry of Environment, Water and Natural Resources (2013). *Analysis of Demand and Supply of Wood Products.* Nairobi. http://www.kenyaforestservice.org/documents/redd/Analysis%20of%20Demand%20and%2Supply%20of%20Wood%20Products%20in%20Kenya.pdf.

Mutimba, S. and Barasa, M. (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainale Charcoal Industry in Kenya*. Energy for Sustainable Development Africa. Nairobi.

Oballa, P.O., Konuche, P.K.A., Muchiri, M.N. and Kigomo, B.N. (2010). Facts on Growing and Use of Eucalyptus in Kenya, Nairobi: Kenya Forestry Research Institute.

Tesot, A. K. (2014). Environmental Implications of the Charcoal Business in Narok-South Sub-County, Narok County, Nairobi Kenya: Kenyatta University.

4.20 Indicator 20. Change in consumption of traditional use of biomass

4.20.1 Definition

(20.1) Substitution of fossil fuels with domestic bioenergy measured by energy content (20.1a) and annual savings of convertible currency from reduced purchases of fossil fuels (20.1b)
(20.2) Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content.

4.20.2 Measurement units

(20.1) MJ per year and/or MW per year;
(20.2) MJ per year

4.20.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

In the tea industry, electricity is used for motive power, refrigeration and air conditioning, as wood is the main source of fuel for the tea curing process. Automotive uses such as tractors and the

company fleets are the main consumers of diesel fuel. Thus, the bioenergy service is targeted to substitute wood in the curing process.

From field visits to tea industry "Y" and briquette manufacturer "X", the average cost per kilogram of briquette is 9,666 KSh/ton, and the cost per ton of fuelwood is 4,181 KSh/ton.

Energy consumption in a typical medium-level tea industry and the corresponding costs are provided in Table 4.59.

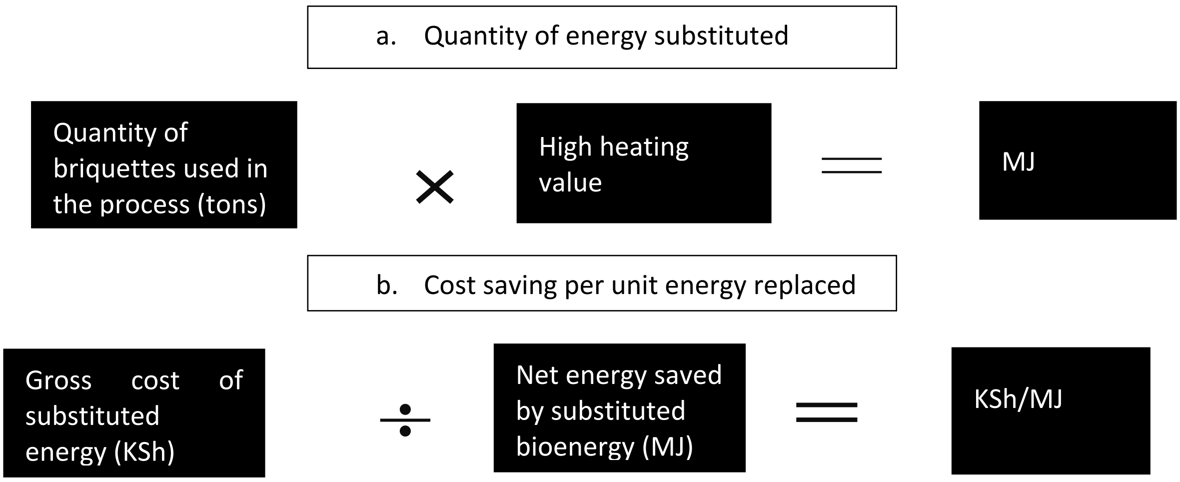
Table 4.59. Energy consumption and cost in tea factory "Y"

	Wood	Electricity	Diesel	Total
MJ	149 696 170	11 818 336	1 674 326	163 188 832
Cost (KSh purchase at farm)	36 349 927	46 700 661	4 450 486	87 501 074
Cost (KSh purchase + transport)	42 764 620	46 700 661	4 450 486	93 915 767
Energy (MJ/kg made tea)	26.1	2	0.3	28.5

Source: Ethical Tea Partnership 2016

To make this assessment, savings in convertible currency should be interpreted considering both the overall impacts on the monetary costs of their energy supply, considering the relative costs of producing or purchasing bioenergy, and the special value of convertible currency (vis-à-vis the national currency) to the country and its economic development. The case study thus estimates energy saving that would have otherwise been needed from the use of firewood by tea industries and the associated cost. This approach is summarised in Figure 4.27.

Figure 4.27. Estimation of energy and cost saving



CHARCOAL

Bioenergy use in the household sector is mainly for cooking. The approach adopts the energy ladder concept describing energy transition based on economic growth. The complete substitution of traditional firewood in urban areas is assumed, as we move up the energy ladder to charcoal. This is a theoretical case.

Charcoal that would be required to completely replace traditional firewood in urban areas is based on percentage access rates in Indicator 14 (bioenergy used to expand access to modern energy services). The 16.2 per cent share of households reported in Indicator 14 using traditional firewood in the urban areas shifts to charcoal for energy and adopts more-efficient cooking technologies. As

such, as the number of households using firewood reduces to zero by 2030, and the saturated share of households using charcoal rises from 82 per cent to 98 per cent. The key assumption is as the same as in Indicator 14. As another assumption, population growth is the main driver of biomass energy demand.

4.20.4 Key findings

BAGASSE BRIQUETTES

Firewood resource replaced with modern bioenergy

From the field visit and taking the case of tea factory "Y", the final energy contribution of sugarcane bagasse briquettes to firewood use is in the ratio of 1:20, as illustrated in Table 4.60.

Table 4.60. Firewood-to-briquette use ratio in tea factory "X"

	Wood (MJ)	Briquette (MJ)
Hourly energy demand mix in factory "Y"	17 050	864.8
Wood: briquette ratio	20	1

Applying the ratio to annual biomass energy requirement in factory "Y", around 490 tons of wood is saved per year (7.4 GJ annually). However, the cost of the briquettes is slightly more than twice as much, as illustrated in Table 4.61.

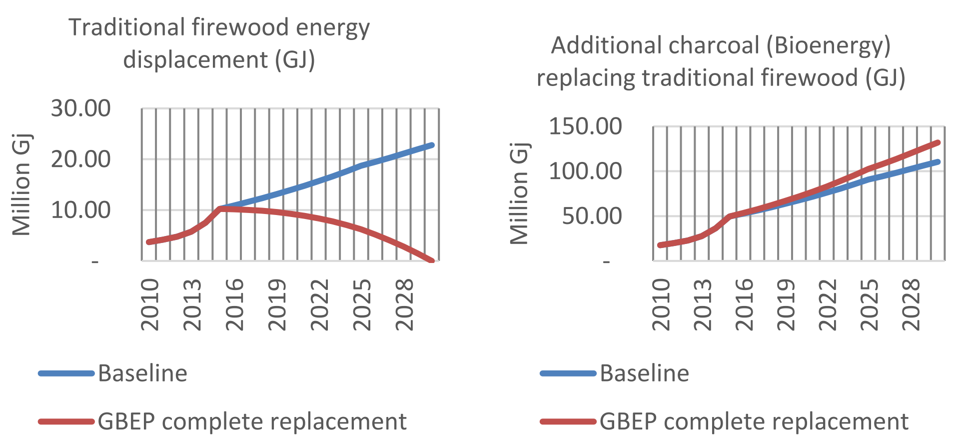
Table 4.61. Cost saving intensity on use of bioenergy for heat generation

	Wood	Briquettes
Cost intensity (KSh/MJ)	0.24	0.69
Additional cost (KSh/MJ)	-	0.45
Energy requirement (MJ)	149 696 170	149 696 170
Biomass cost at factory (KSh)	36 349 927	103 513 309

CHARCOAL

As people's social-economic status changes, households tend to adopt modern cooking devices and to move from primitive fuels such as firewood, cow dung and agricultural waste to advanced fuels. Charcoal, kerosene and coal are considered to be energy in transition (Schlag and Zuzarte 2008).

Figure 4.28. Energy demand in future scenario



Based on these assumptions and projections, the final wood demand in urban areas is 660,000 tons in 2015 and will grow to around 1.5 million tons of wood equivalent (22.8 million GJ) in 2030. Following the energy ladder concept and replacing traditional wood with charcoal use in modern and improved cookstoves (bioenergy), an equivalent of 22.8 million GJ will be replaced with charcoal. This would translate to 0.9 million tons of additional charcoal converted in an improved charcoal kiln of above 35 per cent efficiency level, and would imply a requirement of 2.6 million tons of firewood above the business-as-usual scenario.

4.20.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

Process heating in tea manufacturing is majorly reliant on wood fuel.

Fossil fuels are used for other purposes in tea industries including for transport, motor saws and other moving devices within the factory.

Briquette use in tea industries presents an opportunity to save on cutting down of trees for fuel or harvesting premature wood. Whereas the total final energy requirement in the tea industry is the same, the cost of generating this energy differs by source of energy (wood and briquettes).

For the case study tea industry, around 490 tons of wood is saved. Relating to Indicator 8 (Land use and land-use change related to bioenergy feedstock production), the equivalent of a 40 hectare plantation of trees is saved.

Currently, the cost of briquettes is much higher than the cost of firewood. From the calculation the company spends 45 cents more per MJ yielded from briquette compared to firewood.

The energy cost is a factor of cost of investment, raw materials, production, labour and logistics. Comparing the two cases (use of firewood and use of sugarcane bagasse briquettes) the difference is likely to be borne by equipment investment and running cost, labour and logistics.

Practices and policy to improve sustainability

While there is opportunity in briquettes, the bottlenecks in the processes need to be addressed. Such challenges include import duties on the machinery and equipment to produce the bioenergy, government taxation on bioenergy and access to raw materials. Bagasse and other agricultural residues are considered waste, but access is challenging due to competing uses and transport.

Policy recommendation for enhancement

- Reduce/remove import duties on bioenergy machinery.
- Bioenergy sources such as briquettes and pellets have not been given due consideration as transformative alternative energy sources. The Energy Act of 2019 vaguely mentions them, nor does the draft energy policy of 2015.
- Remove taxation on briquettes.
- Promote the transformation of bagasse and other agri-residue to energy. Although sugarcane bagasse lies in heaps in the factories, accessing it by private investors remains a challenge. Ensuring maximised use of bagasse through environmental regulation will enhance uptake of the waste from factory premises by private investors.

- Promote technological innovation in boiler burners to enhance tea factories' adoption of briquettes. A discussion with Kenya Tea Development Agency pointed out that clinker formation and increased turndown time is one of the major barriers in using briquettes.

Future monitoring

Further monitoring of the bagasse utilization rate from sugarcane industries and the briquette adoption rate in tea factories will be required.

Further monitoring of the cost of production of briquettes and the business value chain also will be required.

CHARCOAL

Synthesis of the findings

Substituting firewood with charcoal would not be considered sustainable due to the multiple losses from harvesting to conversion.

Using firewood directly in improved cookstoves presents additionality rather than converting firewood to charcoal and then using it in the mix of traditional and improved charcoal cookstoves.

Whereas direct use of firewood suffers single conversion loss in cooking stoves, there is considerably more loss of energy in charcoal conversion than in cooking.

Calculations indicate that a factor of five times more wood will be required for charcoal.

Practices and policies to improve sustainability

Charcoal should be considered as a transitional fuel for urban areas as active promotion of substitutes such as LPG is heightened.

It is recommended that promoting direct use of firewood, which is more conservative, will be better in rural households. This would yield positive savings if improved cookstoves are adopted.

Future monitoring

Real transition happens in both supply and demand as the adoption of improved charcoal kilns and improved cookstoves are promoted.

However, techno-financial challenges to the adoption of improved cookstoves should be addressed.

Whereas most modern charcoal cookstoves are high performing in the laboratory, social acceptability and real adoption is fuzzy, with scanty literature assessing the impacts. Technological advancement of non-carbonized biomass combustion is necessary for real sustainability.

4.20.6 References

Ethical Tea Partnership (2016). *Thermal Energy and Briquette Biomass Analysis for KTDA Factories in Muranga County, Kenya.*

Schlag, N. and Zuzarte, F. (2008). *Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature*. Stockholm Environment Institute.

4.21 Indicator 21. Training and re-qualification of the workforce

4.21.1 Definitions

(21.1) Share of trained workers in the bioenergy sector out of total bioenergy workforce, and (21.2) share of re-qualified workers out of the total number of jobs lost in the bioenergy sector.

4.21.2 Measuring unit(s)

Percentage

4.21.3 Overall methodology of the implementation

The following agencies and organizations were contacted to obtain additional data on training and re-qualification of the workers in the bioenergy sector in Kenya: National Industrial Training Authority, Directorate of Occupational Safety and Health Services, State Department of Labour of Kenya, International Labour Organization Kenya and Federation of Kenya employers. Unfortunately, none of these organizations shared any information to be included in the indicator.

4.21.4 Key findings

BAGASSE BRIQUETTES

The renewable energy sector is one of the most dynamic sectors worldwide, and the workforce in the sector needs to undertake training and re-qualification in order to be able to adapt to new technologies and equipment (Africa Institute of South Africa 2012). According to the Africa Bioenergy Policy Framework and Guidelines, an exercise coordinated by the African Union Commission and the United Nations Economic Commission for Africa, one of the key instruments for implementing bioenergy policies is strengthening the capacity of the private sector. This includes capacity building on the installation, operation and maintenance of bioenergy systems (UNECA 2013).

Additionally, the need for trained professionals, especially those working with high-risk equipment, was highlighted in the Kenya Occupational Safety and Health Act of 2007 (GoK 2007).

Data from three bagasse briquetting plants (case studies 1, 2 and 3) and from three tea factories are included in this indicator:

- *Case study 1:* The company reported that the staff working with the production of bagasse briquettes received basic training, including first-aid training and fire response training. The women involved in the bagasse sun drying had not received any training.
- *Case study 2:* The company reported that only those workers operating the briquetting presses had received basic training on the operation of the equipment. Neither the administrative and sales staff nor the women in charge of the bagasse drying had received any training.
- *Case study 3:* Workers received no formal training and only experience on-the-job training.

In the three visited and interviewed tea factories, most boiler operators and maintenance staff had received some kind of training. In some cases, the boiler operators and maintenance staff had received some technical education before their involvement in the company. In addition, both boiler operators and maintenance staff had attended specific training organized by the Kenyan Tea Development Agency on different operational aspects of boilers.

All of the interviewed companies have reported technical challenges when the proportion of bagasse briquettes in the mix of biomass fuel used in their boilers is increased. Firewood is a biomass type

with low content of ash-forming components, with most of the ash-forming components concentrated in the bark. Moreover, the agricultural residues, and particularly bagasse, have a high content of ash-forming components (García López 2016). Ash-forming components, depending mostly on the actual chemical composition and the achieved temperatures in the bed, among other parameters, can be transformed into fly ash, leading to fouling and corrosion or to particulate matter emissions. Ash-forming components can also melt into a thick fluid that solidifies when it cools down, *i.e.,* clinker formation. In addition, the boilers used by the tea factories are boilers originally designed for furnace oil combustion and modified to combust biomass.

There is an obvious need to further study the combustibility of bagasse briquettes in the installed boilers and to determine what kind of modifications or interventions would contribute to better combustion conditions that are more suitable for the fuel-to-boiler interactions. Based on the tremendous experience that the employees at the visited companies have, they control the briquettes-to-firewood ratio that allows them to operate the boiler without the air inlets being obstructed by clinkers. However, more in-depth understanding regarding the fuel-to-boiler dynamics would be a valuable tool for the tea industry, given that it would allow them to incorporate more agricultural residues in their biomass fuel mix.

With regard to specific training on occupational safety and health, and according to the Occupational Safety and Health Act of 2007 (Kenya), the employer is responsible for providing information and training to the employee to ensure health and safety at work[3]. In addition, as described in this Act, all of the operators working with steam boilers should be properly instructed (GoK 2007).

All of the interviewed briquette plants and tea companies reported having occupational health and safety policies as well as annual audits.

CHARCOAL

The people involved in charcoal production learn by doing with people from their families or village. With practice, the people engaged in the wood and kiln preparation become skilled to lead the actual charcoal production.

In the Kenyan charcoal market, some organizations, for instance Kenya Forestry Research Institute, work on introducing modern kiln designs with higher thermal efficiency. Traditional kilns have a thermal efficiency of around 10-15 per cent, whereas the improved ones can achieve a thermal efficiency of around 25 per cent (Mutimba and Barasa 2005; KFS and KEFRI 2014).

Typically, organizations that introduce a modern kiln system also train some of the users to enhance technology adoption by supporting the producers with knowledge.

As described, the most common practice is to use traditional earth kilns. However, the interviewed charcoal producer associations reported that less than 15 per cent of the charcoal producers had received training on charcoal production in modern kilns.

Most drivers involved in the transport of charcoal have a driver's license. Nevertheless, the drivers do not transport exclusively charcoal but also other goods, so the fact that they have received basic training cannot be attributed to the charcoal sector solely.

In general, the only training within the charcoal production sector is on-the-job training from person to person and based on learning by doing. Charcoal production is inefficient from a thermal but also an economic point of view, as well as informal. All of these factors are reasons for why training is very low or non-existent among the charcoal producers.

If the workforce needs to be re-qualified due to regulation of, for instance, the use of traditional kilns, the workforce would engage in charcoal production by using modern kilns. Re-qualifying the workforce to work with biomass gasification could also be a possibility, given that it is a close sector.

Ideally, the moisture content of the wood, size of the wood logs, tree species and other important parameters have to be measured when producing charcoal. However, this is not a common practice when charcoal producers do the kiln preparation. It is assumable that in a more industrialized set-up, those parameters are controlled and therefore the efficiency would be higher.

Standardization of the charcoal sector would enhance the implementation of modern kilns, the training of the charcoal producers, and the adoption of routines and practices on prevention of occupational injuries, and thus would contribute to an increase in the revenue that is shared by the producers.

Currently, regulations on the parameters of the firewood and kiln preparation are non-existent and so are the quality standards of the final product.

4.21.5 Conclusion and recommendations

BAGASSE BRIQUETTES

Synthesis of findings

Training and requalification of the bioenergy sector workforce has been identified by some international organizations as crucial.

Among the interviewed briquetting plants, training is non-existent or minimal. The training level of the tea factories was much higher than of the briquetting plants. However, specific training on combustion-related issues would be valuable for the future of briquette use in boilers.

Practices and policies to improve sustainability

A national plan aiming to standardize the training level of the different actors in the bioenergy sector in general and in biomass briquettes in particular would be a very positive intervention for the sector.

Specific training on combustion-related issues would enhance a better understanding of the problems faced when operating boilers, which were designed for furnace oil and later modified to operate with firewood, with briquettes made with agricultural residues.

Future monitoring

Future monitoring of the training and requalification of the workforce will give updated information of the status of the sector.

Future monitoring will also be important as the sector continues to grow and as new actors appear on both the production and use sides.

CHARCOAL

Synthesis of findings

Overall, training and requalification of the workforce in the charcoal sector in very low or non-existent. Although some organizations and initiatives are promoting improved kilns, training on the use of improved kilns is very low, as is the actual use of improved kilns in the Kenyan charcoal secto

r.

Practices and policies to improve sustainability

Training on the implementation and use of improved kilns has to be accompanied by policies enhancing the use of modern kilns.

Standardization and regulation of the charcoal sector will promote the training and requalification of the workforce in the sector.

Future monitoring

As the sector develops, future monitoring on training and requalification of the task force will be crucial to understand the stability of the sector and to identify areas where more training might be needed.

4.21.6 References

Africa Institute of South Africa (2012). *Energy Transition in Africa*. Edited by Simelane, T. and Abdel-Rahman, M.

García López, N. (2016). *Biomass Utilization for Energy Purposes in Kenya: Fuel Characteristics and Thermochemical Properties.* BSc thesis. Umeå University, Sweden.

Government of Kenya (2007). *The Occupational Safety and Health Act*. Nairobi.

Kenya Forest Service and Kenya Forestry Research Institute (2014). *Drylands Forest Livelihoods: Factsheet No. 2, Charcoal.* Nairobi.

Mutimba, S. and Barasa, M. (2005). *National Charcoal Survey: Summary Report. Exploring the Potential for a Sustainale Charcoal Industry in Kenya*. Energy for Sustainable Development Africa. Nairobi.

United Nations Economic Commission for Africa (2013). *Africa Bioenergy Policy Framework and Guidelines: Towards Harmonizing Sustainable Bioenergy Development in Africa*. Addis Ababa.

4.22 Indicator 22: Energy diversity

4.22.1 Definition

(22.1) Change in diversity of total primary energy supply due to bioenergy.

4.22.2 Measurement unit(s)

Index (in the range 0-1) and MJ bioenergy per year in the total primary energy supply (TPES)

4.22.3 Methodology

Information on energy diversity in Kenya and data required for the calculation of the Herfindahl Index were retrieved from both national and international statistics. Calculation of the Herfindahl Index was done at the national level.

The Herfindahl Index (HI) was calculated using the following formula.

$$\mathrm{HI} = \sum_{n=1}^{n} s^2$$

Where: S_i = Share of energy sources in TPES, n = Number of energy sources in TPES. The Herfindahl Index can range from 0 to 1. HI = 0 when n = ∞, HI = 1 when n = 1 (only one source of energy in TPES, S = 100 per cent). Therefore, a smaller index, closer to 0, indicates higher energy diversity.

4.22.4 Key findings

The total primary energy supply (TPES) was 27 million tons of oil equivalent (IEA 2019), with a bigger proportion being met by bioenergy. Biomass energy is the main source energy, contributing to over 70 per cent of the total primary energy supply, followed by petroleum (17 per cent), geothermal (6 per cent), hydropower (1.7 per cent), wind energy (0.1 per cent) and coal (0.01 per cent).

The resulting Herfindahl Index is as shown in Table 4.62.

Table 4.62. Main results of the Herfindahl Index calculation

Source of energy	Primary energy (ktoe)	Share (S)	S^2
Biomass	17 281	64%	0.4084
Hydro	276	1%	001
Geothermal, wind, solar	4 143	15%	0.0235
Electricity net imports	13	0%	000
Petroleum	4 866	18%	0.0324
Coal	463	2%	003
Total	**27 042**	**HI**	**0.4646**

4.22.5 Conclusions and recommendations

Synthesis of the findings

At the national level, the Herfindahl index is 0.4646. A higher diversity of supply would result in a lower index. The tea industry consumes electricity, fossil fuels and biomass energy, used mainly for tea drying. Biomass, mostly firewood, represents more than 70 per cent of the energy consumed by the tea industry. At the household level, the energy diversity is even smaller since biomass represents 94 per cent of the energy consumed by the residential sector.

Practices and policies to improve sustainability

The high dependence of the energy supply on traditional biomass is risky for energy security. The promotion of modern bioenergy (biogas, bioethanol) and of renewable energy, as well as the accelerated penetration of improved/advanced cookstoves and improved practices to produce charcoal, will contribute to a higher diversity and therefore a higher energy security in Kenya.

Future monitoring

Assessing the diversity of the bioenergy sources in the energy supply of Kenya is useful to measure the benefits of promoting modern bioenergy in the country. A complementary approach could be to measure energy diversity at the household level, where fuel and stove diversity, in other words, fuel and stove stacking, are strategies used by households to guarantee the energy and cooking security of the households.

4.22.6 References

International Energy Agency (2019). Energy statistics of Kenya. https://www.iea.org/statistics/?country=KEN&isISO=true.

4.23 Indicator 23. Infrastructure and logistics for distribution of bioenergy

4.23.1 Definition

(23.1) Number and (23.2) capacity of routes for critical distribution systems, along with (23.3) an assessment of the proportion of the bioenergy associated with each.

4.23.2 Measurement unit(s)

(23.1) number; (23.2) MJ, m^3, or tons per year; or MW for heat and power capacity; and (23.3) percentages.

4.23.3 Overall methodology of the implementation

An overview of infrastructure and logistics in the distribution of bioenergy was performed to determine the number and capacity of routes for critical distribution systems, along with an assessment of the proportion of the bioenergy associated with each. The review was conducted through perusal of official reports and literature regarding infrastructure for production and logistics for the distribution of bioenergy in Kenya. Field visits were conducted to selected tea factories and briquette plants to obtain data and information focused on the production and use of briquettes from sugarcane bagasse in the tea industries and charcoal for use in households.

4.23.4 Key findings

BAGASSE BRIQUETTES

Number of routes for critical distribution systems

The use of bagasse briquettes as an alternative bioenergy source for use by the tea industries has rapidly emerged in Kenya. The main feedstock for briquette production is sugarcane bagasse, available in large quantities mainly in the western sugar-belt region of Kenya.

As shown in Figure 4.29, the infrastructure and logistics in the production and transport of briquettes to the tea factories involves four main processes:

1) collection and transport of bagasse feedstock to briquette plants;
2) production of briquettes;
3) briquette transport and distribution; and
4) end use in tea industries.

The sugar factories, the main source of bagasse feedstock, are concentrated in the western Kenya sugar-belt region, with 11 sugar mills. According to the Sugar Directorate, the amount of bagasse generated by the sugar factories constitutes around 30 per cent of the total sugar cane crushed (AFA-SD 2017). As shown in Table 4.63, over 1.7 million tons of sugarcane bagasse was produced by all 12 sugar factories in Kenya in 2017. Around 60 per cent of the generated bagasse is used internally by sugar mills for their boiler operations, while 40 per cent or around 510,000 tons of bagasse remains unutilized and deposited in open fields and available for other uses including briquette production (AFA-SD 2017). However, specific data on the amount of bagasse supplied to briquette plants were not available at the time of the survey and therefore were not presented in this study.

Figure 4.29. Infrastructure and logistics bagasse briquette production and use in tea industries

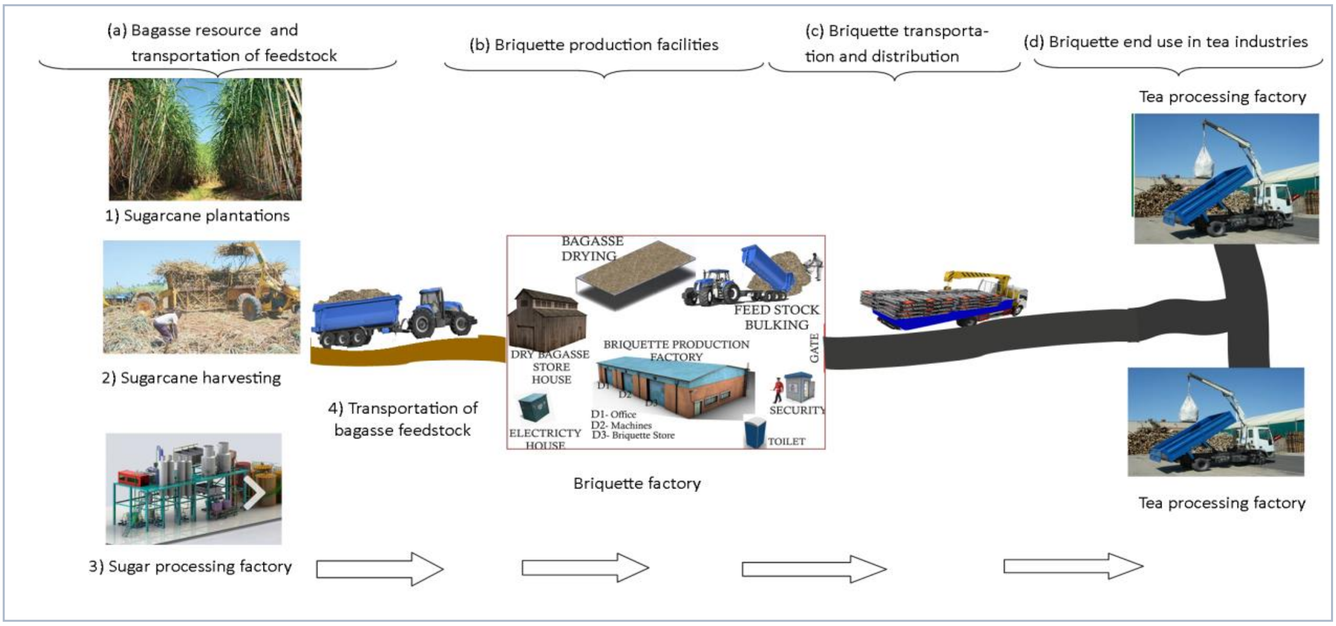


Table 4.63. Sugarcane bagasse production in Kenya

Factory/Year	2013	2014	2015	2016	2017
1. Chemelil	115 391	192 939	159 289	112 922	84 625
2. Muhoroni	149 914	201 625	158 403	133 060	124 444
3. Mumias	696 525	539 116	511 902	395 343	109 642
4. Nzoia	286 439	263 671	266 143	305 921	154 213
5. South Nyanza (Sony)	239 439	224 785	264 974	262 029	163 121
6. West Kenya	341 687	295 690	410 869	326 935	305 800
7. Soin	7 500	3 293	-	-	-
8. Kibos	251 125	192 815	350 088	338 320	254 125
9. Butali	141 760	200 103	182 273	330 862	182 097
10. Transmara	129 705	177 023	178 687	282 105	138 800
11. Sukari Industries	108 853	131 838	126 148	166 330	118 151
12. Kwale International	-	-		114 720	70 130
Total bagasse produced (tons)	2 468 338	2 422 898	2 608 776	2 768 548	1 705 148

Source: AFA-SD 2017

Transport of sugarcane bagasse feedstock to briquette plants

In 2018, there were around seven briquette factories in western Kenya (AFA-SD 2018). Over 75 per cent of the briquette processing facilities operate in the vicinity of sugar processing factories. According to our survey and interviews of three briquette plants in the Nyando and South Nyanza sugar belts of western Kenya (referred to hereafter as Factory A, Factory B and Factory C) (Field survey 2019), two main routes for feedstock transport to briquette processing facilities were identified and described as follows: Route 1 involves the collection and transport of bagasse by road using 7-12 ton tractors within a 1.5 kilometre radius and 28-ton trucks for longer distances of 82 kilometres from briquette plants; Route 2 involves the use of a conveyor belt for the briquette factory integrated within the sugar factory. For this second route, the distance covered is assumed to be 0 kilometres.

Table 4.64 shows the transport of the bagasse feedstock to briquette factories and the associated energy consumption. The first road transport scenario, in the case of briquette plants in Kisumu County, which currently has over five plants, is shorter within an average of 1.5 kilometres, requiring almost 3.6 MJ/ton. However, the total transport distance in the case of the second scenario of feedstock acquisition is much longer, with an average of 82 kilometres, requiring almost 72.16 MJ/ton. The second scenario occurs during feedstock scarcity in the three nearby sugar mills of Chemelil, Muhoroni and Kibos in Kisumu County. The two options for road transport mean that if one source of feedstock is disrupted due to maintenance or contractual challenges, then other sources could be used without disruption of deliveries to briquette factories, albeit with energy and cost implications.

Table 4.64. Transport of bagasse feedstock to briquette factories and associated energy consumption

Briquette factory/location	Location of feedstock source	Distance (km)	Transport means	Number of routes	Energy consumed MJ/ton
Factories A and B (Kisumu County)	Region 1: Nyando sugar belt	1.5	12-ton tractor	1	3.6
	Region 2: Western sugar belt	82	28 -ton truck	1	72.16
Factory C: (Narok County)	Region 3: South Nyanza sugar belt	0	Conveyor belt	1	N/A

Source: Field survey 2019

In the western sugar-belt region of Kenya, there are around seven factories that produce non-carbonized briquettes for industrial applications (AFA-SD 2017). Bagasse feedstock transport benefits from infrastructure development support financed by the European Union in the sugar belts. The purpose of the infrastructure development was to open up the road transport network in the sugarcane-growing areas. The all-weather road network provides accessibility of the bagasse feedstock from the sugar mills to briquette factories. Overall, the road network developed as a result of infrastructure development support has contributed to other development of the sugarcane-growing regions of western Kenya.

Briquette processing facilities and transport for use by tea industries

Sugarcane bagasse briquettes are produced in central production facilities. The plants either are integrated within sugar factories or are stand-alone facilities. Different technologies and infrastructure are used depending on the scale of operation (KEFRI 2018). The general process involves agricultural residue (bagasse) drying, storage of dry bagasse, briquetting, and packaging and storage of the final product. According to the information obtained during the field visits, bagasse drying is the most difficult step in bagasse briquette production from a logistical point of view. While small-scale briquette plants use open sun drying, with local labour, large plants use either a combination of manual labour and rotary dryers or purely highly mechanized rotary dryers. The production depends on the type of drying capacity and the scale of the plant.

Transport of briquettes to end use in the tea industries involves three main actors: producers; transporters and consumers. From our field survey and interviews, while most briquette companies supply directly to tea factories, others prefer to sell briquettes through intermediaries / distributor chains that in turn supply to the industry (Field survey 2019).

Table 4.65. Briquette production and distribution

Briquette factory	Production capacity (annual tons)	Distribution routes (number)	Actual production in tons	Amount of briquettes in tons supplied to tea industries	Share of briquettes produced and supplied to tea factories (%)
Factory A	2 000	2	250	0	0%
Factory B	22 000	2	10 295	4 509	44%
Factory C	15 000	2	907	416	46%

Source: Field survey 2019

Table 4.66 shows case studies of two briquette factories and the volume of briquettes supplied to tea industries between 2015 and 2018.

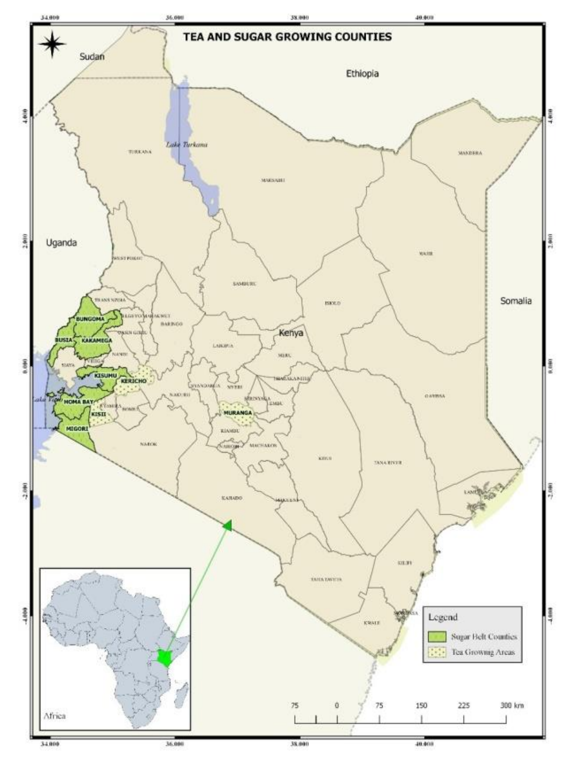
Table 4.66. Sugarcane bagasse briquettes and distribution in 2015-2018 (briquette factories A and B)

Year	Tons of briquettes sold per year		Tons of briquettes sold to tea industry		Per cent of briquettes sold to tea industry	
	Briquette factory A	Briquette factory B	Briquette factory A	Briquette factory B	Briquette factory A	Briquette factory B
FY 2014-2015	722	8 868	360	60	50%	1%
FY 2015-2016	907	10 295	416	4 509	46%	44%
FY 2016-2017	846	10 614	149	504	18%	5%
FY 2017-2018	1 230	10 680	13	2 503	1%	23%

Source: Field survey 2019

Case studies of the briquette and tea factories visited during the survey identified the use of roads as the main mode of transport for the delivery of the briquettes to the tea factories. In the South Nyanza sugar belt, comprising the three sugar mills of Transmara, Sony and Sukari Industries, there are five briquette factories in operation (Maps 4.8 and 4.9). The briquette plants benefit directly from a well-developed road network for the distribution of briquettes. There exist all-weather roads to the tea factories in Kisii and Kericho highlands, with an average distance of 19 kilometres (Table 4.67). In addition, the tea industries have well-developed road networks within their areas of operation for their green leaf delivery. Distribution of briquettes to the tea factories has the benefit of three main highways leading to the town of Kisii: the Migori-Kisii-Kericho, Kisumu-Kericho and Nakuru-Murang'a highways.

Map 4.8. Tea- and sugarcane-growing counties in Kenya



Map 4.9. Road network in Kenya

Source: AFA 2018

Table 4.67. Distribution of sugarcane bagasse briquettes to tea industries and associated energy consumption

Briquette factory location	Destination to tea factories	Distance (km)	Transport means	Number of distribution routes	Energy consumed MJ/ton
Nyando sugar belt (Kisumu County)	Region 1: Aberdare Ranges	334	28-ton truck	1	294
	Region 6: Kisii Highlands	75	28-ton truck	1	66
	Region 7: Nandi Hills and Western Highlands	82	28-ton truck	1	72
South Nyanza sugar belt (Narok County)	Region 1: Aberdare Ranges	320	28-ton truck	1	281.6
	Region 6: Kisii Highlands	19	28-ton truck	1	17
	Region 7: Nandi Hills and Western Highlands	125	28-ton truck	1	110

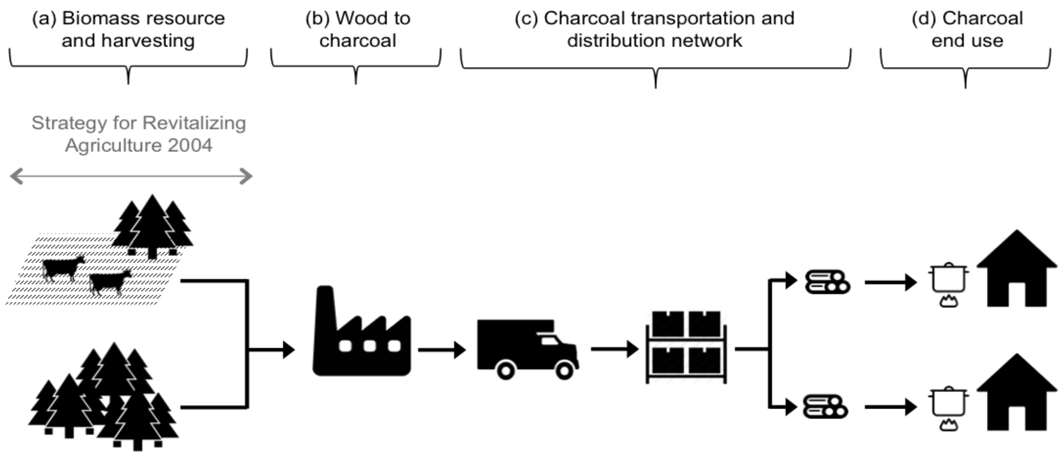
Source: Field survey 2019

CHARCOAL

Overall chain

Charcoal is produced in strategic locations near feedstock sources. There are several charcoal production technologies in Kenya. The most common charcoal supply chain consists of three levels. First the transporters visit the production site or a designated collection point with a motorized or non-motorized means of transport and buy the charcoal in bulk. They then transport the charcoal to vendors (wholesale or retail), mostly in urban areas.

Figure 4.30. Charcoal value chain



Source: Edited from SEI

Transport and distribution of charcoal to end use in households

Transport of charcoal in Kenya to end use involves several means. Logistics in the end use involves market and sales in urban and peri-urban areas. At the markets, charcoal is sold in different bags and tins by vendors. Considering charcoal from Kitui and Narok counties, the average distance to the main distribution areas in Nairobi City ranges between 175 kilometres and 220 kilometres. Carious regions of destinations within Nairobi City for charcoal from Kitui County are shown in Table 4.68. The lower-end actors (producers) have the shortest distance to collection centres, while the total transport distance to Nairobi is much longer with an average of 175 kilometres, requiring almost 392 MJ/ton using 12-ton trucks. Higher logistical challenges contribute to higher prices for charcoal in Nairobi, which consumes 10 per cent of the total charcoal volume in Kenya.

Table 4.68. Distribution of charcoal for household use in Nairobi City County

Sub-county	Distance from Kitui County (km)	Total quantity in sacks	Per cent
Kibera	175	638	18%
Kangemi	175	700	19%
Langata	175	421	12%
Embakasi	175	862	24%
Ngara	175	992	27%
TOTAL		3 613	100%

Source: Onekon and Kipchirchir 2016

According to Onekon and Kipchirchir (2016), major distribution centres in Nairobi were in Kibera, Kangemi, Langata, Embakasi and Ngara. Charcoal packaging depends on the region and recyclable bags in the area. In the distribution centres within Nairobi City, charcoal is stocked in 35 kilogram sacks; while in others in small 50 to 90 kilogram bags. On one end there are outlets for bulk purchases using bags, and at the other end are small-scale retailers, found within very close proximity to households. The small-scale retailers mostly sell charcoal in small units, the common being the 2-kilogram tin.

4.23.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

Feedstock transport

For use of sugarcane bagasse briquettes by the tea industry, feedstock transport was either through conveyors for briquette plants integrated within the sugar mills or delivered using trucks or tractors for stand-alone production plants.

In the Nyando sugar belt of Kisumu County, bagasse is obtained from sugar processing mills located in sugarcane-growing areas.

The transport route used for supplying the bagasse from the sugar mills to processing plants is a well-developed road network and in a good state.

There are several options for bagasse feedstock transport to briquette factories, and no bottlenecks have been found that contribute to the value chain. The second scenario considered in this analysis (where bagasse feedstock is transported from the sugar mills to briquette factories) is assumed to be the current situation, given that the reliability of feedstock delivery outweighs the extra costs of longer transport distances.

For the briquette factories, the bagasse feedstock is transported through Kakamega and Kisumu to the plants in Kibos. Total transport of around 82 kilometres implies an energy consumption of about 72 MJ/ton on average.

Bioenergy transport to end use

In the case of the use of sugarcane bagasse briquettes by the tea industry, the bioenergy is transported by truck through two possible transport routes by the roads that are classified as National route 1A and National route 1B.

The efficiency of briquette transport depends on the region of destination. The briquettes supplied to the tea factories located in the Aberdares and Mount Kenya highlands is transported from the briquette factories located in either the Nyando or South Nyanza sugar belts. In both cases, briquette transport takes place over a long distance (334 kilometres) using trucks of 28-ton capacities and therefore implies high costs in terms of energy (294 MJ/ton), which is not cost effective.

However, briquette factories located in the South Nyanza belt of the country supplying tea factories in Kisii Highlands have shorter routes, thus spending comparatively lesser amounts of energy.

Practices and policies to improve sustainability

Currently, the feedstock is transported over long distances before reaching the briquette factories. This is more so because first, bagasse is delivered from long distances from sugar mills (second scenario).

As consumption of briquettes will increase in the near future due to high demand by tea industries, feedstock delivery directly from the sugar mills will likely become more reliable and the first scenario considered in this analysis will likely become common. In this scenario, transport distance is much shorter, thus reducing energy consumption and transport cost.

Currently briquette transport is mostly carried out by truck, travelling over long distances in order to be delivered to the tea factories located in Mount Kenya highlands.

Other means of transport, such as train, should be considered to increase the amount of fuel delivered and reduce the related energy consumption and environmental impact. As the sector grows over the coming years, thanks to the ongoing standard railway development, larger investments in trains for briquette transport could become more feasible.

Future monitoring

Infrastructure and logistics for the distribution of bioenergy can significantly affect the development of the sector. The tea industry is a major consumer of firewood in Kenya.

The use of bagasse briquettes provides an opportunity as an alternative bioenergy source for the industry. Yet in 2018, only 500 tons of briquette fuel was consumed by the tea factories. Briquette consumption was projected to increase in 2018, following the government moratorium that banned logging on public and community forests.

The briquette factories and tea factories will need to optimize their infrastructure and logistic systems to deal with this increased demand. However, specific data on the amount of bagasse supplied to briquette factories were not available at the time of the survey.

Further, the private sector needs to invest in more cost-effective and environmentally friendly bagasse feedstock handling, including drying, which is a major logistical challenge.

CHARCOAL

Synthesis of the findings

Feedstock transport

For the charcoal pathway, feedstock for charcoal production is located in areas where trees are harvested. This is because the kilns are often mobile. Therefore, energy consumption is minimal and was not considered.

Bioenergy transport to end use

Charcoal is transported by trucks from two production hotspots in Kenya's drylands of Kitui and Narok counties.

The lower-end actors (producers) have the shortest distance to collection centres, while the total transport distance to Nairobi is much longer with an average of 175 kilometres, requiring almost 392 MJ/ton using 12-ton trucks. Higher logistical challenges contribute to higher prices for charcoal in Nairobi, which consumes 10 per cent of the total charcoal volume in Kenya.

Practices and policies to improve sustainability

For charcoal, there is a need to increase the raw material supply by introducing extension and technical assistance programmes to bring about sustainable management of existing indigenous forests, woodlots and rangeland trees now being used for charcoal production. Such programmes would aim at creating a more stable supply of trees through economic incentives to the tree farmer and a revision of tree prices.

Further, there is a need to shift existing production methods to improved systems with higher efficiencies. For charcoal distribution, the most common transport problem occurs during the rainy

season when the roads to charcoal kilns are impassable. At this time the fuel price in Nairobi may unofficially jump 30-40 per cent above normal.

Another problem is the high cost of imported fuel and vehicle maintenance in charcoal transport. These problems could be solved by introducing a modal split in transport. This would require the establishment of central depots on the major all-weather roads in charcoal-producing areas.

The smaller-capacity trucks now used for long-haul to Nairobi would be restricted to supplying these depots, especially during the dry season, when charcoal making is at a peak.

From the depots, the charcoal would be transported to Nairobi on trailer trucks with greater capacity than those now used. Thus, on long hauls, trailers would transport 600-700 bags of charcoal on one trip as opposed to the 200-300 bags now transported.

The short-haul – depot – long-haul mode could cut the cost of transport reportedly by at least 30 per cent. As supply distances from Nairobi increase, it may become either extremely expensive or wholly uneconomical to transport charcoal in loads of fewer than 400 bags per truck.

Future monitoring

For the charcoal pathway, currently, the demand for charcoal in Kenya is set to increase following the 2018 moratorium, posing a danger for importation of the bioenergy from neighbouring countries such as Uganda and Tanzania.

Charcoal producers from sustainably managed plantations, transporters and distributers will similarly need to optimize efficiencies in both infrastructure and logistics based on the projected demand for charcoal for the growing urban population.

Therefore, the measurement of this indicator for both the bioenergy pathways in the future is very important to determine potential bottlenecks and to understand where efficiency savings can be achieved.

4.23.6 References

Agriculture and Food Authorities (2018). *Map of tea and sugarcane growing counties in Kenya*. MAI, Nairobi, Kenya.

Agriculture and Food Authority, Sugar Directorate (2017). *Year Book of Statistics 2017*. Nairobi.

Agriculture and Food Authority, Sugar Directorate (2018). *Survey of Briquette Production Using Sugarcane Bagasse in the Sugar belt Regions of 2018.* MAI, Nairobi, Kenya.

Kenya Forestry Research Institute (2018). Kenya Forestry Research Institute Strategic Plan 2018-2022.

Onekon, W.A. and Kipchirchir, K.O. (2016). Assessing the effect of charcoal production and use on the transition to a green economy in Kenya. *Tropical and Subtropical Agroecosystems* 19, 327-335.

4.24 Indicator 24. Capacity and flexibility of use of bioenergy

4.24.1 Description

(24.1) Ratio of capacity for using bioenergy compared with actual use for each significant utilization route.
(24.2) Ratio of flexible capacity which can use either bioenergy or other fuel sources to total capacity.

4.24.2 Measurement unit(s)

Ratios

4.24.3 Overall methodology of the implementation

BAGASSE BRIQUETTES

For bagasse briquettes, capacity and flexibility were analysed at the level of the tea industry and the briquette producers. The necessary information was found in field study through visits, official statistics and in literature. In particular, in order to measure the indicator, data were compiled on the current share of use of sugarcane bagasse briquettes by the tea industries, and information was gathered related to the maximum level of briquettes/bioenergy blending with firewood that can be tolerated by the existing boilers without retrofitting.

CHARCOAL

For charcoal, data on the current share of the bioenergy for use in households along with other bioenergy data were determined. Sub-indicator 24.2 was not captured.

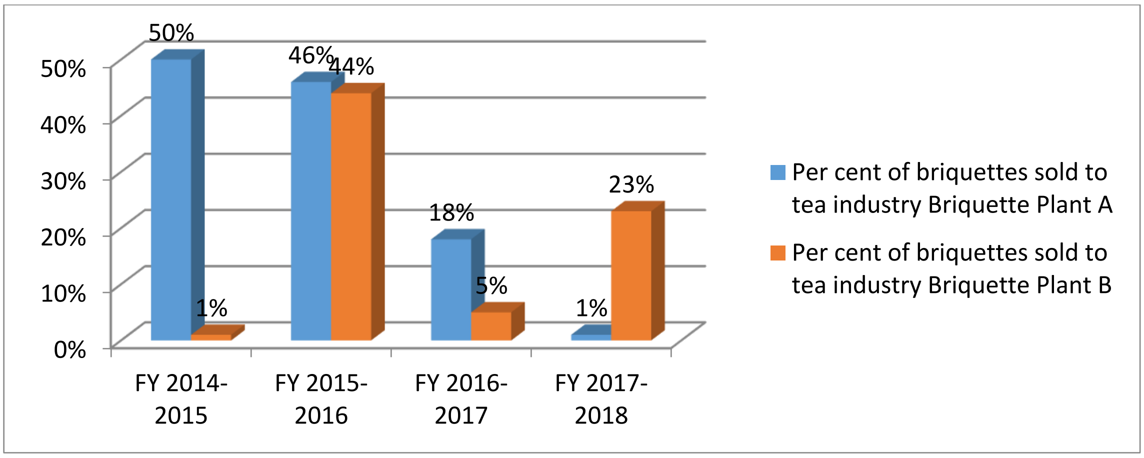
4.24.4 Key findings

BAGASSE BRIQUETTES

According to the two briquette plants based in Kisumu and Narok and visited during the project, briquette sales to tea factories occurred and were highest during the 2015-2016 financial year, with an average of 45 per cent of their sales to tea factories (Figure 4.31). The share of briquettes sold to the tea industry rose between the 2014/2015 and 2015/2016 financial years, then sharply decreased in 2016/2017 and increased in 2017/2018 (Figure 4.31). In other words, the flexibility of the briquette factories to sell briquettes to the tea industry is high.

During the 2014/2015 and 2015/16 financial years, there was a push for use of briquettes along with firewood by Kenya Tea Development Agency. The decrease in 2016/17 was due to both technical/operational (clinkers) and economic (higher prices, logistics) challenges. Sales picked up again in 2018 after the moratorium, with tea factories blending briquettes with firewood. The government moratorium, banning logging in public and community forests in 2018, led to an acute shortage of wood fuel in the country. As a result, most tea industries started to seek alternative bioenergy sources for their boilers including bagasse briquettes.

Figure 4.31. Share of briquettes sold to the tea industry



Source: Field visits 2019

Also from field visits, in FY 2017-2018, a tea factory in Murang'a consumed around 579 tons of briquettes in the blend of 7,167 tons of firewood (Table 4.69). Briquettes represent around 7.5 per cent of the mix (or 8 per cent of the quantity of wood).

Table 4.69. Capacity ratios of bagasse briquettes share in tea industries (tea factory C)

Year	Tons of bone-dry firewood	Tons of briquettes used
2014-2015	5 646	268
2015-2016	5 259	176
2016-2017	2 205	0.0
2017-2018	7 167	579
2018-2019	9 589	80

Source: Field visits 2019

According to field visits and discussion with stakeholders, the tea factories could run on sugarcane bagasse briquettes blends of 20 per cent with 80 per cent firewood without the need for retrofitting of their boilers.

Moreover, the energy consumption in the tea industry is dependent on a number of factors including annual crop volumes, operational efficiencies of the factories and the quality of bioenergy (firewood and briquettes).

Assuming that the current boilers could run on blends of around 20 per cent briquettes without the need for retrofitting, up to 200,000 tons of briquettes could be absorbed per year by the tea industry in Kenya.

CHARCOAL

In Kenya, charcoal plays an important role in contributing to the capacity and flexibility of bioenergy through adopting energy-efficient cookstoves. In 2018, the annual consumption of charcoal was around 2.6 million tons (MENR 2016). Charcoal use in Nairobi is widespread, at 10 per cent of the estimated volume consumed in Kenya (Njenga et al. 2013). Around 33.8 per cent of households in Nairobi use improved stoves for cooking, while 9.7 per cent still use more inefficient charcoal stoves.

The existence of charcoal and stove stacking within distributor outlets and kiosks gives flexibility to households for cooking.

Table 4.70 shows the usage shares of various cookstoves in Kenya, disaggregated between rural and urban settings over a 10-year period. The table shows a 0.3 per cent reduction nationally in use of the improved Jiko stove that uses charcoal over the 10-year period from 2005/2006 to 2015/2016. However, use of the ordinary Jiko increased 2 per cent at the national level.

Table 4.70. Percentage usage of various cookstoves used in Kenya and disaggregated between rural and urban settings over a 10-year period

	KIHBS 2005/2006			KIHBS 2015/2016		
	National	Rural	Urban	National	Rural	Urban
Traditional three-stone fire	60.8%	78.0%	9.1%	46.4%	71.7%	13.7%
Improved traditional three-stone fire	8.4%	10.9%	1.0%	8.2%	12.8%	3.0%
Ordinary Jiko	7.1%	4.0%	16.6%	9.1%	5.7%	13.5%
Improved Jiko	6.5%	3.9%	14.3%	6.2%	3.7%	9.3%
Kerosene stove	12.8%	2.3%	44.7%	13.9%	2.2%	29.0%
Gas cooker / LPG	3.4%	0.6%	11.7%	13.3%	2.4%	27.5%
Electric cooker	0.4%	0.2%	1.3%	0.3%	0.1%	0.6%
Other	0.6%	0.3%	1.3%	1.8%	0.9%	2.9%

Source: Ministry of Energy and Clean Cooking Alliance 2019

4.24.5 Conclusions and recommendations

BAGASSE BRIQUETTES

Synthesis of the findings

The assessment noted that each year, the 113 tea industries in operation in Kenya use around 1 million tons of bone-dry firewood or 4.4 per cent of national consumption.

Data and information from the tea factories visited indicate that tea factories are quite flexible and that sugarcane bagasse briquettes can be blended with firewood up to 20 per cent without retrofitting the existing thermal boilers for tea processing.

Practices and policies to improve sustainability

There is a need to consider re-designing existing thermal boilers to accommodate briquettes to achieve higher blending ratios of more than 20 per cent.

The increased briquette consumption at 20 per cent blending would save about 200,000 tons of bone-dry firewood, corresponding to 363.64 m^3 of wood fuel in Kenya.

Future monitoring

The future monitoring of briquettes used in the tea industries depend on the credibility of data from both briquette production and consumption. Additional data should be sourced from tea factories, Kenya Tea Development Agency, AFA-TD, KIRDI, KEFRI and universities.

CHARCOAL

Synthesis of the findings

Research, development and dissemination work on improved charcoal stoves has resulted in the introduction of different stove modes.

In Kenya, around 33.8 per cent of households use improved stoves, while 9.7 per cent still use more inefficient charcoal stoves for cooking.

The existence of charcoal and stove stacking within distributor outlets and kiosks gives flexibility to households to cooking.

Practices and policies to improve sustainability

In order for Kenya to improve on consumption of charcoal from sustainable sources, there is a need to consider fuel and stove stacking accompanied with incentives to accelerate uptake of clean cooking.

Future monitoring

Future monitoring of the charcoal industry in Kenya depends on data on both charcoal production and consumption.

There is a need for additional data from charcoal producer groups and associations, Kenya Forest Service, Kenya Forestry Research Institute and universities / research institutions on the quantities of charcoal produced and consumed as well as the efficiencies of production systems and cookstoves.

Further comprehensive data on stove uptake are necessary.

4.24.6 References

Ministry of Energy and Clean Cooking Alliance (2019). *Kenya Cooking Sector Study: Assessment of the Supply and Demand of Cooking Solutions at the Household Level*. https://www.eedadvisory.com/wp-content/uploads/2019/11/moe-2019-cooking-sector-study-.pdf

Ministry of Environment and Natural Resources (2016). Natural Forest Programme of Kenya. Nairobi.

Njenga, M., Karanja, N., Munste, C., Iiyama, M., Neufeldt, H., Kithinji, J. and Jamnadass, R. (2013). Charcoal production and strategies to enhance its sustainability in Kenya. *Development in Practice* 23(3), 359-371. DOI:10.1080/09614524.2013.780529.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Kenya, with a population of around 48 million people, is the fourth largest economy on the African continent. The country's gross domestic product in 2018 was $88 billion, or $1,202 per capita. The energy mix of Kenya is dominated by biomass (76 per cent), followed by oil and oil products (17 per cent), geothermal (6 per cent) and other renewables (below 6 per cent). Biomass contributes a large share of Kenya's final energy demand, supplying more than 90 per cent of rural household energy needs. The main sources of biomass in the country include charcoal, wood fuel and agricultural waste. Sustainability of the bioenergy sector is central to Kenya's aspirations to achieve middle-income status by 2030 and to contribute to the Paris Agreement, as per the Nationally Determined Contribution (NDC) and the Climate Change Act (2016).

The Government of Kenya has identified substantial potential for power generation using forestry and agro-industry residues, including sugarcane bagasse. Opportunities within sugar factories are estimated to reach 300 MW but have not been exploited. Other bioenergy uses in Kenya include biogas, fuelwood, briquettes, pellets and charcoal. The full potential to achieve sustainable biomass production in the country is still under-developed.

Sustainability indicators were applied to two bioenergy pathways selected in consultation with stakeholders. The data were assessed from both primary and secondary sources, particularly from field visits to bioenergy producers and users, such as briquette companies, tea factories, county governments, and charcoal producers and distributors. The indicators that were applied to the two pathways were assessed and validated with stakeholders.

5.1.1 Bagasse briquettes

This bioenergy pathway focused on the use of sugarcane bagasse briquettes in the tea industry in Kenya as an alternative to firewood. The demand for firewood for use in the tea industry is around 1 million tons each year. The briquetting industry is rising rapidly as a potential source of livelihood, as well as fuel for industrial, institutional and domestic use (Indicators 11, 12, 14). Major consumers of non-carbonized briquettes include the tea industry, schools and hospitals, the tobacco industry and the vegetable oil processing industry, among others.

The bagasse potential is very high in Kenya. The country's 12 sugar mills generate around 2.4 million tons of bagasse annually that remain unutilized (Indicator 8). Production of the briquettes begins with the collection of agricultural residues from millers and farmers. The feedstock is then dried either in the open air or in industrial rotary systems at high temperatures to reduce the moisture content to less than 15 per cent, and then is compressed at high pressure to form briquettes (Indicators 17, 23).

The analysis of the bioenergy pathway's life cycle greenhouse gas emissions (Indicator 1) was based on a case study of a briquette-producing company in western Kenya that supplies briquettes to tea producers. The emissions in the bioenergy pathway are around 1.0 grams of CO_2-equivalent higher per MJ (or 21 per cent higher) compared to the reference case (the use of firewood from eucalyptus). Around 64 per cent of the emission intensity is from briquette transport, followed by manufacture (28 per cent) and combustion (8 per cent). In the reference case, harvesting and chopping of wood chips contributes to 72 per cent of total emission intensity, followed by transport (15 per cent) and combustion (13 per cent).

The bagasse briquettes contribute to 5 per cent of the annual final energy demand of the tea industry. This is estimated at 490 tons of wood equivalent per year (7,400 MJ/year). Although the

use of briquettes saves around 490 tons per year of wood resource, the economic cost intensity of obtaining similar energy from briquettes is around three times more compared to firewood (Indicators 1, 18, 23, 24).

Regarding environmental impacts, the industrial use of briquettes in tea factories has positive impacts. It is expected to result in a gradual reduction in the consumption of primary wood biomass (indicators 3, 8) obtained from forests and woodlands, thereby contributing to biodiversity conservation (Indicator 7). While water quality is not directly impacted by the production of briquettes, the use of the sugarcane bagasse, which otherwise remains in piles next to the mills, avoids leachates and emissions.

On the social indicators, job creation and improved livelihoods were also analysed. Because briquetting is a new sector, new jobs have been created through the whole value chain, and they tend to be formalized with contracts and agreements (Indicators 11, 12). Nevertheless, the sector is based mainly on unskilled jobs, but the tea industry is providing training and requalification of work, particularly for the boilers (Indicators 16, 21). The role of women in the briquette value chain so far has been limited to the sun drying of bagasse.

From an economic point of view, the tea sector is interested in using briquettes to replace fuelwood, but this may require the technical improvement of boilers. The government's moratorium, banning logging in public and community forests in 2018, led to an acute shortage of wood fuel in the country. As a result, most tea industries started to seek alternative bioenergy sources for their boilers, including bagasse briquettes (Indicator 24).

5.1.2 Household use of charcoal produced on woodlands and farmlands

Demand for charcoal is increasing rapidly in Kenya due to population growth, increased urbanization and the development of cottage industries. Today an estimated 2.5 million tons of charcoal are produced in the country annually, up from 1.6 million tons in 2005. There are 253,808 charcoal producers nationwide, up 27 per cent from the estimated number in 2005 (Indicators 8, 9, 12).

In Kenya, charcoal is produced mainly from arid and semi-arid lands, which includes the counties of Baringo, Elgeyo Marakwet, Garissa, Kajiado, Kilifi, Kitui, Kwale, Laikipia, Makueni, Mount Elgon, Narok, Nyandarua, Tana River, Tharaka Nithi and Turkana. The tree species preferred for charcoal production are acacia species (definition of the pathway). Nairobi is the county that consumes the most charcoal in Kenya, and 70 per cent of this charcoal is produced mainly in Kitui and Narok (Indicators 3, 18, 23). Deforestation of many areas in Kenya affected biodiversity and soils as well as water cycles (Indicators 2, 5, 6, 7). For this reason, Kenya introduced a ban on charcoal production in 2018, but charcoal is still produced from woodlands and farmlands.

Regarding non-greenhouse gas emissions, two case scenarios were assessed: highly efficient processes, and business as usual. The gases and particle emissions may be reduced through three key measures: 1) shifting from the use of fresh wood that has a moisture content of around 50 per cent to air-dried wood that has a moisture content of around 20 per cent; 2) low to high adoption of improved kilns (from 10 per cent to 80 per cent in adoption) and stoves (from 38 per cent to 80 per cent); and 3) reducing the transport distance from two-way to one-way, where trucks ferry goods to the charcoal production sites and carry charcoal to the city on their way back (Indicator 4).

In Kenya, around 80 per cent of the population use solid fuels for cooking, often in rudimentary and inefficient stoves with poorly operating chimneys or none. Around 39 million people, or 87 per cent of the population, are affected by household air pollution, which resulted in an estimated 13,900 to 15,140 deaths in 2016 (Indicator 15). Furthermore, through adoption and sustained use of improved cookstoves integrated with on-farm sourcing of firewood, households can save 33.2 per cent of fuel from 2,704 kilograms to 1,806 kilograms per year and 76 per cent of time spent sourcing the fuel.

Sourcing firewood on-farm translates to 64 per cent less time spent on firewood collection due to the shorter distance walked to firewood collection sites (Indicator 13).

Nearly half a million people work in Kenya's charcoal sector, which generates more than $427 million annually (Indicator 19), but it is not considered part of the country's formal economy.

The charcoal sector is dominated by informal jobs. In the charcoal value chain, the role of women is related mainly to kiln preparation for charcoal production and to charcoal retail, whereas transport and wholesaling are heavily dominated by men.

5.2 Recommendations and future monitoring

The application of the Global Bioenergy Partnership indicators to the two pathways contributed to several achievements and final recommendations.

Achievements

- **Consolidation of data from different organizations, ready to be monitored and updated.** Kenya has many organisations working and providing funds to bioenergy, mainly to promote clean cooking, which makes the information polarised and many times not publicly available. Therefore, it is recommended that the national government create a database using the outcomes of this project, which will provide additional information for the Bioenergy Policy currently under development.

- **Assessment of several possibilities to promote the use of modern biomass for energy purposes.**
  This is an important issue, as the current market provides different options to users (particularly for cookstoves) and for the production of briquettes for industrial use. Nevertheless, there is not yet an uptake of many of the more advanced technologies, due mostly to economic reasons. Therefore, it is recommended that incentives are considered, particularly for industrial use. For cookstoves, strong actors in the country, such as the Clean Cooking Alliance, could also start to look at other potential users at the industrial level.

- **Capacity building on the application of the 24 GBEP Sustainability Indicators and the calculation of greenhouse gas and non-greenhouse gas emissions.**

  This effort has included researchers, Kenyan government officials, academics and other stakeholders. The use of two case studies using solid biomass has made it possible to provide input to the databases used in the European Union that calculate greenhouse gas emissions. Therefore, it is recommended that the new values be published and used in new databases.

- **Demonstration of the links to the bioeconomy and the circular economy, especially with the emerging briquette production sector.**

  Several companies in different sectors (e.g., vegetable oil, bakeries) are moving to use alternative biomass feedstocks (macadamia shells, coffee husks) due to the increased cost of fuelwood following the 2018 ban in Kenya. This has led to the use of more innovative feedstocks. The problem remains in the distance required to transport these feedstocks for use in other sectors and regions. Therefore, it is recommended to map out all biomass availability in Kenya to be used by region and by sector.

Policy recommendations

- **The policy environment in East Africa is moving more towards supporting the use of bioenergy in a more sustainable form.**
  During the final stages of this project, there were two important policy developments: the launches of a Bioeconomy Strategy for Eastern Africa (BiSEA project) and a Bioenergy Strategy for East Africa. Although both started at different moments, they share strong synergies and should not be treated as totally separate. The information collected in the 24 GBEP indicators is useful for both initiatives, and therefore it is strongly recommended that synergies are identified and that activities and developments, particularly in the policy arena, are harmonized.

- **Updated and continued monitoring of the data is needed to help Kenya move more rapidly towards a modern and sustainable bioenergy sector.**

  This will require a champion to foster these activities. The support from the Ministry of Energy and the Ministry of Environment should be ongoing to avoid losing momentum in the construction of this database. Other important actors in the country, particularly donors, should be encouraged to work together and bring coherence to the activities in the bioenergy sector in Kenya. Despite the multitude of efforts, they have proved insufficient in providing access to modern forms of bioenergy. However, a common goal of monitoring the success and failures of all programmes on the basis of the GBEP indicators will allow for better input from all activities conducted in the sector.

The Global Bioenergy Partnership (GBEP) project provides technical assistance to government officials and experts in Ethiopia and Kenya to assess the sustainability of their bioenergy sectors and build their capacity for long-term, periodic monitoring of these sectors. Work is structured around the application and interpretation of the 24 indicators to assess the environmental, social and economic impacts of bioenergy production and use. Results from the indicators can be used to inform the decision-making process.

The GBEP Indicators were developed in a collaborative process, led by the Food and Agriculture Organization of the United Nations, which currently hosts the GBEP Secretariat.

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