UN environment programme

SUSTAINABILITY OF BIOGAS AND SOLID BIOMASS VALUE CHAINS IN ETHIOPIA

Results and recommendations from implementation of the Global Bioenergy Partnership Indicators

TECHNICAL REPORT

Ethiopian Environment and Forest Research Institute (EEFRI)
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FOREWORD

Fellow citizens, partners and colleagues,

I am delighted to present the report *Sustainability of Biogas and Solid Biomass Value Chains in Ethiopia: Results and Recommendations from Implementation of the Global Bioenergy Partnership Indicators.*

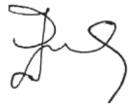
Ethiopia is one of the fastest growing economies in Africa, and with this has come increased demand for energy services. Ethiopia's energy sector is highly dependent on biomass (firewood, charcoal, crop residues and animal dung). Its high reliance on solid biomass for cooking and heating, coupled with rapid population growth and an increased demand for agricultural output (land for crop production and livestock feed) has reduced access to solid fuels. Moreover, the unsustainable use of these fuels is associated with deforestation and resultant land degradation. This is compounded by rising demand for charcoal in urban areas – where households use primarily charcoal for heating purposes – as well as by high demand for wood and agricultural residues in rural households.

To break this downward cycle, Ethiopia's second national energy policy specifically calls for the integration of environmental sustainability into the country's energy production and supply. This policy outlines the need to enhance Ethiopia's bioenergy supply and to increase efficiency in this sector. It is under this mandate that the Environment, Forest and Climate Change Commission (EFCCC) has engaged in this work to begin assessing the sustainability of Ethiopia's bioenergy sector with the use of the Global Bioenergy Partnership (GBEP) bioenergy sustainability indicators.

The 24 GBEP indicators assess the environmental, social and economic impacts of bioenergy value chains. In this pilot study two critical pathways were chosen: 1) biogas from animal dung used by households and 2) solid biomass (firewood and charcoal) used in improved cookstoves for cooking and heating. The report outlines the current and future potential of Ethiopia's bioenergy sector and presents the key results and conclusions. Report results also illustrate important factors that can shape the long-term and periodic monitoring aspects of the sector.

It is my sincere hope that these findings will help improve our overall knowledge and understanding about Ethiopia's bioenergy sector and will serve as a starting point to improve the sustainability of this sector and support the design of effective sustainable bioenergy policies as part of low-carbon development strategies.

This work was undertaken by the Environment, Forest and Climate Change Commission (EFCCC) and the Ethiopian Environment and Forest Research Institute (EEFRI), 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).



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ABBREVIATIONS AND ACRONYMS

°C	Degree Celsius
BCE	Biogas construction enterprise
BEST	Biomass Energy Strategy
BUS	Biogas Users' Surveys
CEC	Cation exchange capacity
CFPME	Construction and fuelwood production and marketing enterprise
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
CRGE	Climate Resilient Green Economy Strategy
CSA	Central Statistical Agency
EBES	Ethiopian Biomass Energy Strategy
EEA	Ethiopian Energy Agency
EEFRI	Ethiopian Environment and Forest Research Institute
EFCCC	Environment, Forest and Climate Change Commission
EPA	Environmental Protection Authority
EPRDF	Ethiopian People's Revolutionary Democratic Front
EREDPC	Ethiopian Rural Energy Development and Promotion Centre
FAO	Food and Agriculture Organization of the United Nations
FDRE	Federal Democratic Republic of Ethiopia
g	Gram
GBEP	Global Bioenergy Partnership
GDP	Gross domestic product
GGGI	Global Green Growth Institute
GHG	Greenhouse gas
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GTP	Growth and Transformation Plan
GW	Gigawatt
GWP	Global warming potential
HI	Herfindahl Index
ICLS	International Conference Labor Statisticians
IEA	International Energy Agency
IFEU	Institut für Energie-und Umweltforschung Heidelberg
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
ICS	Improved cookstoves
IWMI	International Water Management Institute
kg	Kilogram
km^2	Square kilometre
kWh	Kilowatt-hour
ktoe	Kilotons of oil equivalent
L	Litre
LCA	Life cycle analysis
LHV	Low heating value
LPG	Liquefied petroleum gas
LULC	Land use and land cover
m^3	cubic metre
MEFCC	Ministry of Environment, Forest and Climate Change

MoWIE	Ministry of Water Irrigation and Electricity
MSWG	Multi-stakeholder working group
Mtoe	Million tons of oil equivalent
NBPE	National Biogas Programme of Ethiopia
NFSDP	National Forest Sector Development Program
NGO	Non-governmental organization
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
ODI	Overseas Development Institute
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PFM	Participatory Forest Management
PM_{10}	Particulate matter 10 micrometres or less in diameter
$PM_{2.5}$	Particulate matter 2.5 micrometres or less in diameter
PPP	Purchasing power parity
PV	Photovoltaic
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
SNNPR	Southern Nation Nationalities and People's Region
SO_2	Sulphur dioxide
t	Ton
toe	Tons of oil equivalent
TPES	Total primary energy supply
TWh	Terawatt-hour
UNEP	United Nations Environment Programme
WRB	World Reference Base for soil sciences

1 IMPLEMENTATION OF THE GBEP SUSTAINABILITY INDICATORS FOR BIOENERGY IN ETHIOPIA

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

<table>
<tr><th colspan="2">ENVIRONMENTAL PILLAR</th></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td>INDICATOR NAME</td><td>INDICATOR DESCRIPTION</td></tr>
<tr><td>1. Lifecycle greenhouse gas emissions</td><td>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</td></tr>
<tr><td>2. Soil quality</td><td>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</td></tr>
<tr><td>3. Harvest levels of wood resources</td><td>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</td></tr>
<tr><td>4. Emissions of non-greenhouse gas air pollutants, including air toxics</td><td>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</td></tr>
<tr><td>5. Water use and efficiency</td><td>▪ 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</td></tr>
<tr><td>6. Water quality</td><td>▪ 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</td></tr>
<tr><td>7. Biological diversity in the landscape</td><td>▪ 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</td></tr>
<tr><td>8. Land use and land-use change related to bioenergy feedstock production</td><td>▪ 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</td></tr>
</table>

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: ○ skilled/unskilled ○ 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 is 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 (EAC 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 Ethiopia

The objective of applying the GBEP Sustainability Indicators for Bioenergy in Ethiopia 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 Ethiopia. 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. Biogas produced from animal dung and used by households for cooking and heating.
2. Solid biomass (charcoal, firewood) used in improved cookstoves for cooking and heating.

The application of the GBEP indicators was entrusted to a team of experts from the Ethiopian Environment and Forest Research Institute (EEFRI) supported by the Environment, Forest and Climate Change Commission (EFCCC). EEFRI was in turn 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 Ethiopia were shared with stakeholder and national representatives during the final workshop, held on 4 November 2019 in Addis Ababa. 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 Ethiopia. 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 Ethiopia, 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

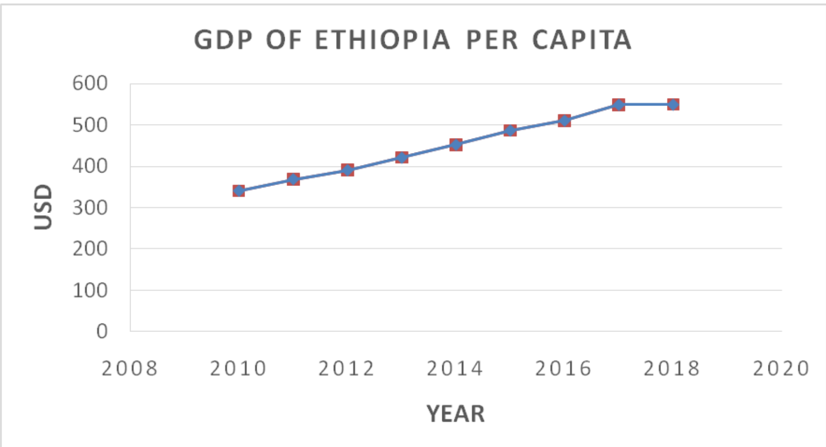
2.1 Overview of Ethiopia

Ethiopia is considered one of the largest and most densely populated countries in Africa. Located in the Horn of Africa, it is a rugged country split by the Great Rift Valley (Ethiopian History 2011). The current population is around 108 million based on the latest United Nations estimates. Around 20.6 per cent of the population is urban (22,180,245 people in 2018). The current population is around 49.8 per cent male and 50.2 per cent female, and the median age is 18.8 years (Ethiopian Population Statistics 2018). The total Ethiopian land area is 1 million square kilometres (km^2), and the population density is 108 persons per km^2 (279 persons per square mile). Ethiopia accounts for around 1.41 per cent of the world population and has the third largest population in Africa.

Ethiopia lies between the Equator and the Tropic of Cancer, between 3° N and 15° N latitude and 33° E and 48° E longitude. The country's total border is 5,328 kilometres and the adjacent countries are Djibouti, Eritrea, Kenya, Somalia and Sudan (Geography 2018). The climate of Ethiopia is varied in terms of geographic location and elevation, with three major climatic zones: Cool Zone, at elevations above 2,400 metres, where temperatures vary from near freezing to 16°C; Temperate Zone, at elevations from 1,500 to 2,400 metres, with temperatures ranging from 16 degrees Celsius (°C) to 30°C; and Hot Zone, at elevations below 1,500 metres with daytime temperature variations from 27°C to 50°C. The rain conditions are normal with the rainy season from mid-June to mid-September (longer in the southern highlands) preceded by sporadic rain showers from February or March; the other months of the year are usually dry (Ethiopian Climate 2018).

Ethiopia is also one of the poorest countries in Africa, with a per capita income of $783. According to official statistical data, the country's economic growth was around 10.5 per cent on average between 2003/04 and 2016/17. Real per capita gross domestic product (GDP) more than doubled from $32 billion in 2010/11 to $81 billion in 2016/17, and per capita income doubled from $396 to $862 in the same period. The gross national income per capita in Ethiopia was a reported $1,890 in 2017, according to the World Bank's development indicators, compiled from officially recognized sources. The share of the population living below the national poverty line decreased from 30 per cent in 2011 to 24 per cent in 2016 (World Bank 2018). The youth unemployment rate is 7 per cent, and 25 per cent of youth aged 15 to 29 are reported to be underemployed. Unemployment among urban youth is at 29 per cent (Ethiopia Central Statistical Agency 2014).

Figure 2.1. Ethiopian gross domestic product (GDP)



Source: Tradingeconomics.com/World Bank

2.2 Environmental situation

The major environmental issues facing Ethiopia include frequently occurring drought, flooding, soil erosion, deforestation and depletion of soil nutrients that has a serious negative impact on farmland, livestock and overall nutrition. Ethiopia has suffered from severe drought and population displacement in a period of less than two years. As a result, around 2.7 million people require assistance to access drinking water; an estimated 5.6 million people need emergency food aid; around 2.7 million pregnant woman, children and lactating mothers demand supplementary food and feeding; and around 1.9 million households require livestock assistance (Office for the Coordination of Human Affairs 2017; United Nations International Children's Emergency Fund [UNICEF] 2018).

Among sub-Saharan African countries, Ethiopia has a high level of soil erosion (Mekonnen *et al*. 2015). A study by Hurni *et al*. (2015) showed that the rate of soil erosion was 20 mg/ha/year on cultivated lands, and a rate of soil erosion of around 42 mg/ha/year has been reported across the country on cultivated lands (Haregeweyn *et al.* 2017). Around 47 mg/ha/year rate of soil erosion has been a serious problem in the Upper Blue Nile Basin (Gelagay and Minale 2016).

Due to the heavy reliance of the economy on rain-fed agricultural and pastoral activities, Ethiopia is vulnerable to severe food shortages and famines. Moreover, the country faces a number of challenges to development, including limited access to education, high disease and death rates and lack of food security (Ethiopia Climate Vulnerability Profile 2018).

2.3 Agriculture and livestock

Agriculture makes significant contributions to the country's gross domestic product (GDP). It accounts for around 40.0 per cent of GDP, around 80.0 per cent of total exports and 80 per cent of total employment in the country (Matousa, Todob and Mojoc 2013). Other important sectors are service, contributing around 40 per cent, and industrial sectors, contributing 15.0 per cent (The World Factbook 2016).

Ethiopia has around 51.3 million hectares of arable land. However, only around 20 per cent is currently cultivated by smallholders, whereas more than 50 per cent of all smallholder farmers and pastoralists operate on less than 1 hectare. Moreover, Ethiopia has great potential for the production of coffee and accounts for over 3 per cent of the global coffee market. Coffee is by far the largest foreign exchange earner in Ethiopia, and the country exported about 190,734 metric tons in 2013/14 earning $749 million. Overall agricultural production (i.e., cereals) increased by 45 per cent (European Union Business Forum in Ethiopia 2015). Maize is one of the most important crops in Ethiopia, and the country is the second biggest maize producer in Africa.

Ethiopia's livestock population is considered the largest in Africa and the tenth largest in the world. The sector accounts for around 10 per cent of Ethiopia's export income, with leather and leather products constituting around 7.5 per cent and live animals 3.1 per cent. The country is home to about 17 million head of sheep, 22 million head of goats, 49 million head of cattle and 38 million chickens. The country also has demonstrated potential for fishery development in its rivers, reservoirs and freshwater lakes. Additional areas of potential investment in the agricultural sector include fish, meat and milk processing, and the raising and fattening of cattle, goat, sheep and camel (Ethiopia Ministry of Industry 2016).

2.4 The energy situation

2.4.1 Resources and supply

Ethiopia is endowed with renewable and sustainable energy sources. These include hydropower and, to a lesser extent, wind, geothermal and solar as well as biomass. The approximate potential for hydropower is around 45 gigawatts (GW), for wind is 10 GW and for geothermal is 5 GW, and solar irradiation ranges from 4.5 kilowatt-hours (kWh)/m^2/day to 7.5 kWh/m^2/day (Mondal *et al*. 2018). Only a small amount of the renewable energy potential is harnessed today.

The annual production of electricity is around 11,000 gigawatt-hours mainly generated from hydropower (93 per cent) followed by wind energy (7 per cent), and around 1.6 per cent of this production is exported. Most of the energy supply for the transport sector is imported in the form of liquid petroleum (International Energy Agency [IEA] 2018).

Table 2.1. Ethiopian energy production capacities per sources of energy in 2014
(Assuming optimal conditions of the installed power plants)

Sources of energy	Energy production capacity [kWh]	Energy production capacity (%)	Energy production capacity per capita [kWh/capita]
Hydropower electricity	20.97×10^9	86%	199.83
Renewable energy (biomass, solar, wind energy)	2.7×10^9	11%	25.56
Fossil fuels	0.7×10^9	3%	6.97
Total	*24.39×10^9*	*100%*	*232.36*

Source: Statistics of Ethiopia. Available at: https://www.worlddata.info/africa/ethiopia/index.php.

2.4.2 Energy indicators

The key indicators describing the energy situation of Ethiopia in 2016 are provided in Table 2.2.

Table 2.2. Ethiopian energy indicators for 2016

Parameter	Value	Unit
Population	102	Millions
GDP	52	Billion 2010 $
GDP PPP	161	Billion 2010 $
Energy production	48	Mtoe
Net imports	4	Mtoe
TPES	52	Mtoe
Electricity consumption	9	TWh
CO_2 emissions	11	Mt CO_2

Parameter	Value	Unit
TPES/population	0.50	toe/capita
TPES/GDP	0.98	toe/thousand 2010 $
TPES/GDP PPP	0.32	toe/thousand 2010 $
Electricity consumption / population	0.09	MWh/capita
CO_2/TPES	0.21	t CO_2/toe
CO_2/population	0.11	t CO_2/capita
CO_2/GDP	0.21	kg CO_2/2010 $
CO_2/GDP PPP	0.07	kg CO_2/2010 $

Source: IEA World Energy Balances 2018. Available at: https://www.iea.org/statistics/?country=ETHIOPIA&year=2016&category=Renewables&indicator=RenewGenBySource&mode=table&dataTable=INDICATORS.

2.4.3 Consumption

The final energy consumption of Ethiopia was an estimated 42,148 kilotons of oil equivalent (ktoe) in 2016, of which around 92 per cent was consumed by domestic appliances, 4 per cent by the transport sector, 3 per cent by industrial sectors and around 1 per cent by others. Bioenergy accounts for most of the energy supply, and the domestic use of energy commonly stems from unsustainable sources.

There are notable differences in the rate of electricity access in urban and rural areas of the country. In urban areas, around 87 per cent of the population has access to electricity (Mondal *et al*. 2017), whereas in rural areas electricity access is extremely low at around 5 per cent of the population (World Bank 2015).

Eighty-three percent of the population resides in rural areas, relying largely on traditional biomass energy sources (i.e., firewood, crop residues and dung) for cooking and heating. Biomass energy sources account for 91 per cent of final energy consumed, petroleum for around 7 per cent, and electricity for only 2 per cent (IEA 2018). Biomass covers over 98 per cent of total energy consumption in the residential sector, and electricity accounts for only around 2 per cent of total energy consumption.

Ethiopia's total electricity consumption was 6.35 terawatt-hours (TWh) in 2013, and increased to around 9.14 TWh in 2016 (IEA 2018; Mondal *et al*. 2017), whereas net energy imports were around 3.02 million tons of oil equivalent (Mtoe) in 2013, 3.5 Mtoe in 2014 and increased to 3.71 Mtoe in 2015 and 3.99 Mtoe in 2016 (IEA 2018). Due to population pressure and rapid economic growth, the demand for energy is rising tremendously. The country's demand for electricity in particular is predicted to grow by around 10-14 per cent per year until 2037 (Ethiopian Electric Power Corporation 2013).

2.4.4 Energy balance

Ethiopia can almost fulfill its energy demand with domestic energy production. Energy production and consumption as well as energy exports play great roles in the country's economic growth, and other sources of energy such as refined petroleum and coal are imported and utilized (Table 2.3).

Table 2.3. Ethiopian energy balance for 2016

	Coal [1]	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Electri-city	Heat	Total [2]
	ktoe	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*	*ktoe*
Production	0	0	0	0	0	895	70	47 048	0	0	48 013
Imports	272	0	3 729	0	0	0	0	0	0	0	4 001
Exports	0	0	0	0	0	0	0	0	-15	0	-15
International marine bunkers [3]	0	0	0	0	0	0	0	0	0	0	0
International aviation bunkers [4]	0	0	-471	0	0	0	0	0	0	0	-471
Stock changes	0	0	7	0	0	0	0	0	0	0	7
Total primary energy supply	**272**	**0**	**3 265**	**0**	**0**	**895**	**70**	**47 048**	**-15**	**0**	**51 535**
Transfers	0	0	0	0	0	0	0	0	0	0	0
Statistical differences	0	0	-19	0	0	0	0	0	0	0	-19
Electricity plants	0	0	-1	0	0	-895	-70	0	965	0	-1
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0
Heat plants	0	0	0	0	0	0	0	0	0	0	0
Gas works	0	0	0	0	0	0	0	0	0	0	0
Oil refineries	0	0	0	0	0	0	0	0	0	0	0
Coal transformation	0	0	0	0	0	0	0	0	0	0	0
Liquefaction plants	0	0	0	0	0	0	0	0	0	0	0
Other transformation	0	0	0	0	0	0	0	-9 174	0	0	-9 174
Energy industry own use	0	0	0	0	0	0	0	0	-29	0	-29
Losses	0	0	0	0	0	0	0	0	-164	0	-164
Total final consumption	**272**	**0**	**3 245**	**0**	**0**	**0**	**0**	**37 874**	**757**	**0**	**42 148**
Industry	272	0	792	0	0	0	0	0	261	0	1 326
Transport	0	0	1 734	0	0	0	0	6	0	0	1 741
Other	0	0	626	0	0	0	0	37 867	496	0	38 989

Residential	0	0	289	0	0	0	0	37 490	284	0	38 064
Commercial and public services	0	0	59	0	0	0	0	377	206	0	642
Agriculture / forestry	0	0	139	0	0	0	0	0	0	0	139
Fishing	0	0	0	0	0	0	0	0	0	0	0
Non-specified	0	0	139	0	0	0	0	0	6	0	144
Non-energy use	0	0	93	0	0	0	0	0	0	0	93
-of which chemical/petrochemical	0	0	0	0	0	0	0	0	0	0	0

(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 World Energy Balances 2018. Available at:
https://www.iea.org/statistics/?country=ETHIOPIA&year=2016&category=Renewables&indicator=RenewGenBySource&mode=table&dataTable=BALANCES.

2.4.5 Energy policies

Growth and Transformation Plan

The Growth and Transformation Plan (GTP) of the Ethiopian Government (Mengistu *et al*. 2015), which is guided by the green economy strategy (Federal Democratic Republic of Ethiopia [FDRE] 2011), includes the development and dissemination of alternative energy from renewable sources such as biomass, solar photovoltaic (PV) cells, wind, geothermal and hydropower electricity. In compliance with this strategy, biomass-based energy consumption has been the first alternative for rural areas.

Furthermore, the green growth strategy stipulates measures to be taken to mitigate greenhouse gas emissions and save energy. The measures include the promotion of efficient light bulbs, with the goal of achieving 100 per cent penetration; dissemination of fuel wood efficiently; the distribution of improved cooking stoves, with a target of 11.45 million set for the GTP-II period of 2016-2020; afforestation of 2 million hectares and reforestation of 1 million hectares by 2030 (FDRE 2011; Ministry of Environment, Forest and Climate Change [MEFCC] 2016).

Climate policies

The Nationally Determined Contribution of Ethiopia to climate change mitigation includes a 64 per cent reduction in greenhouse gas emissions from the business-as-usual scenario in 2030. This is equivalent to a reduction of 255 million tons of carbon dioxide equivalent ($MtCO_2$ eq.) from the projected business-as-usual emissions of 400 $MtCO_2$eq. (FDRE 2017). Emissions in 2010 were 150 $MtCO_2$eq, emitted by livestock sector (42 per cent of the total), deforestation and forest degradation due to the cutting and burning of fuel wood and due to logging (37 per cent), crop cultivation (9 per cent), end-use sectors (9 per cent) and power generation (3 per cent).

The plan to mitigate greenhouse gas emissions is built on the following four pillars:

1. Improving crop and livestock production practices for greater food security and higher farmer incomes while reducing emissions;
2. Protecting and re-establishing forests for their economic and ecosystem services, while sequestering significant amounts of carbon dioxide and increasing the carbon stocks in landscapes;
3. Expanding electric power generation from renewable energy;
4. Leapfrogging to modern and energy efficient technologies in transport, industry and building sectors.

Sustainable development and energy policies

Ethiopia issued several policy and strategic documents aimed at ensuring attainment of the Sustainable Development Goals (SDGs). The forefront ones are the Climate Resilient Green Economy Strategy (CRGE) for addressing both climate change adaptation and mitigation objectives, Ethiopia's National Energy Policy and the Biomass Energy Strategy. Among these policies and strategies:

- *The Green Economy Strategy* has prioritized programmes that could help to develop sustainable forestry and reduce fuelwood demand (i.e., reduce demand for fuel wood through distribution and usage of fuel-efficient stoves or via alternative-fuel cooking and baking techniques such as liquefied petroleum gas (LPG), electric or biogas stoves) contributing to forest management, enhanced carbon sequestration, reduction of forest degradation, afforestation and reforestation of woodlands (Susanne *et al*. 2013). Predominantly, the Ethiopian Ministry of Water, Irrigation and Electricity is in charge of implementing these programmes.

- *The National Energy Policy* aims to increase the sustainable and renewable sources of energy (i.e., bioenergy supply) and enhance the efficiency of bioenergy use. In February 2013, the Ministry of Water, Irrigation and Electricity published and adopted the final draft strategic plan for the national Energy Policy of the country. Its major objective is to increase the efficiency of biomass fuel utilization, facilitate the shift to greater use of modern fuels, address household energy problems by promoting agro-forestry and integrate environmental sustainability into energy production and supply systems (Ethiopia Communicating Policy 2018).

The policy also states that the country will not depend only on hydropower to increase the supply of electricity, but also take advantage of other renewable and sustainable energy resources such as solar panels, geothermal energy and wind power. Moreover, the country needs to encourage energy conservation in major energy-consuming sectors such as transport, industry and others while ensuring that energy development is environmentally friendly and sustainable; and to provide appropriate encouragement for the private sectors (Energypedia 2018). The draft national energy policy of 2013 is yet to be endorsed by the Council of Ministers.

- *The government of Ethiopia* has also developed its sustainable bioenergy policy as an essential constituent of the strategy of the national development programme, with decent legal provisions for the promotion of environmentally friendly energy sources (i.e., establishment of biofuels production and processing industries), distribution and utilization of biofuels across the country, replacement of fossil fuels used in transport sectors and mitigation of climate change (Abreham and Belay 2015).

Status of liquid biofuels

Over the past two decades, Ethiopia has been looking to expand its energy capacity (Gebreegziabher and Mekonnen 2011). The government's recently issued biofuel strategy aims to encourage domestic biofuel production, with the goal of decreasing reliance on expensive fossil oil imports (Ethiopia Ministry of Mines and Energy 2007).

The biofuel strategy was developed and endorsed by the Council of Ministers in 2007 during a time of high universal enthusiasm for biofuels because of record high oil costs. Explicit goals incorporate substituting oil powers with biofuels; creating jobs and raising wages through biofuel feedstock creation, handling, and conveyance; and decreasing the emissions of ozone-depleting substances via substitution of oil by biofuels. Key procedures for gathering destinations incorporate technology transfer and research and development; generation of advanced ethanol from sugarcane molasses and biodiesel from Jatropha, castor oil and palm oil; expanding biofuel use for vehicles and for cooking; guidelines on the side of change to biofuels including measures and mixing mandates for vehicles. Cross-sectoral issues incorporate solid partner commitments, universal collaboration, effective coordination and initiatives (including a biofuel gathering), and expanding the fund for biofuel advancement (MEFCC and Netherlands Development Organisation [SNV] 2018).

Biofuel ventures exist in various locales of Ethiopia, with an emphasis on bioethanol and biodiesel generation. In addition, Ethiopia set a target for a 5 per cent mix of bioethanol in vehicle fuel in 2008, which was raised to 10 per cent a few years later. Authority reports show that by mixing more than 38.2 million litres of bioethanol with fuel, the nation had the option to save $30.9 million on oil imports since 2008 (Biofuelsdigest 2013). Despite the fact that the recently launched Climate Resilient Green Economy strategyenvisages 5 per cent biodiesel blending in transport fuel by 2030 (FDRE 2011), biodiesel mixing in vehicle fuel has not yet begun in the country. As a component of the arranged large-scale development in the sugar business that is stipulated in the national Growth and Transformation Plan (GTP), Ethiopia also aims to produce 181,604 cubic metres of bioethanol from sugar by-products (from molasses) towards the end of the GTP period 2010/11-2014/15 (Ministry of Mines and Energy 2010).

The most common liquid biofuels produced are biodiesel and bioethanol. The potential for producing fuel alcohol from molasses and other raw materials, including trees such as eucalyptus, is large in Ethiopia. The country has high potential for biodiesel production (Gebremeskel and Tesfaye

2008). The current biofuel development strategy emphasizes the production of bioethanol from sugar beet, sugar cane, sweet sorghum and others, and biodiesel from jatropha and castor. The country has an estimated potential area of about 25 million hectares of land suitable for production of biodiesel feedstock (Gebremeskel and Tesfaye 2008).

Ethiopia has good agro-climatic conditions for sugarcane production, high productivity per hectare (around 150 tons/ha), and high sucrose content (10-14 per cent). There are currently 13 sugar mills, of which 8 are completed and 5 are in development. It takes around 1 ton of molasses to produce 250 litres of ethanol. Ethiopia currently produces 28 million litres of ethanol per year across two plants, with a third being developed; it is imperative for Ethiopia to de-carbonise its transport sector in order to achieve global climate change mitigation. Bioethanol from sugarcane is also a potential solution for aviation biofuels (RSB 2018). In 2016, biofuel production in Ethiopia was 0.35 thousand barrels per day. Biofuel production increased from 0 thousand barrels per day in 2002 to 0.35 thousand barrels per day in 2016, growing at an average annual rate of 34.17 per cent (Knoema 2019).

Bioethanol from sugarcane molasses was produced for the first time at Finchaa Sugar Factory. Production of bioethanol increased from 299,444 litres in 2001 to 13 million litres in 2011 (Sugar Corporation 2014; Shemelis *et al*. 2013). In 2010/11 annual production of Finchaa sugar estate reached 8 million litres, while that of Metehara was 12.5 million litres. Ethiopia is establishing several sugar estates, and nine were to start production by 2014/15. When the new factories commence production and the expansion to Wonji, Metehara and Finchaa is complete, the annual production of bioethanol from sugarcane molasses will be substantially increased (Gaia Association 2014).

At the Ethiopian Development Research Institute (EDRI), the biofuels venture review was led by the Environmental Economics Policy Forum for Ethiopia (EEPFE) in 2010. As indicated by this review, there are around 15 biofuels companies, including non-governmental organisations (NGOs), involved in biofuels production in Ethiopia. The overview demonstrated that two companies are at the product testing stage and only one company exported biodiesel at least once. The rest are still at a much younger stage. The survey also determined that complementary local innovations are occurring in the biofuels sector, including the invention of biodiesel stoves, processors/distilleries and biogas-driven vehicles.

Finchaa Sugar Factory Ethanol Plant has an installed capacity of 450 hectolitres of pure alcohol per day. The calculations of the net present value and internal rate of return of the project show that production of bioethanol from molasses is economically viable at current prices. With the assumption that the impact of all other factors is the same for both products, cost examination based on energy content demonstrates a cost savings of 0.36 Ethiopian birr per litre of ethanol, supplanting imported lamp oil in the cooking needs of family units. Yearly cost savings from the task's ethanol supply are around 3.2 million birr at full plant limit. In comparative advantage assessment, the calculated domestic resource cost figure of 9.70 is less than the shadow exchange rate (11.58 birr per $1) signifying that the domestic production cost is less than the import cost. The actual incentive included through bioethanol generation over the time frame undertaken is 175 million birr (Temesgen 2018).

Developing bioethanol plants related to existing and upcoming sugar manufacturing plants is in progress. The Ethiopian Minerals, Petroleum and Bio Fuel Development Corporation and Sugar Corporation, both open ventures, likewise declared that they will set up a 1.1 billion birr ethanol industry to produce 50,000 litres of ethanol per day. The joint venture of the two undertakings will be set up at Omo Kuraz III, a sugar industrial facility developed by Complant, which is relied upon to begin preliminary test before the part of the arrangement year (Yewondwossen 2018).

Decision process in energy policies

The formulation and implementation of a sustainable and renewable energy policy requires consideration of several issues such as national and regional level cooperation on energy investment; social, environmental, political and cultural interaction among institutions across the country; participation of stakeholders; and financial development. Strong commitment and capacity is also required to enforce regulatory policies at the federal and regional levels, and to this effect the Ministry of Water, Irrigation and Electricity is in charge of implementing the energy policies. Moreover, the national bioenergy policy can be incorporated and integrated into national energy and national macroeconomic developmental strategies, the transport sector, and agriculture and industrialization strategies while ensuring linkage among the regional and federal government for the ease of policy enforcement.

2.5 References

Abreham, B. and Belay, Z. (2015). Biofuel energy for mitigation of climate change in Ethiopia. *Journal of Energy and Natural Resources* 4(6), 62-72.

Energypedia (2018). https://energypedia.info/wiki/Ethiopia_Energy_Situation. Accessed 8 November 2018.

Ethiopia Central Statistical Agency (2014). *Ethiopia Mini Demographic and Health Survey.* Addis Ababa.

Ethiopia Climate Vulnerability Profile (2018). https://www.climatelinks.org/resources/ethiopia-climate-vulnerability-profile. Accessed 3 November 2018.

Ethiopia Communicating Policy (2018). https://blogs.ubc.ca/misrak509/. Accessed 8 November 2018.

Ethiopia Ministry of Industry (2016). https://infomineo.com/agriculture-in-ethiopia-3/. Accessed 3 November 2018.

Ethiopia's Climate Resilient Green Economy (2016). http://www.ethcrge.info/crge.php. Accessed 6 November 2018.

Ethiopian Geography (2018). https://aethiopien-botschaft.de/?page_id=181. Accessed 3 November 2018.

Ethiopian History (2011). http://www.selamta.net/history.htm.

Ethiopian Climate (2018). https://www.historycentral.com/nationbynation/Ethiopia. Accessed 3 November 2018.

Ethiopian Population Statistics (2018). http://www.worldometers.info/world population/ethiopia-population/. Accessed 4 November 2018.

European Union Business Forum in Ethiopia (2015). *Ethiopian Economic and Trade Report.* Addis Ababa. http://bit.ly/2a1uQY6.

Federal Democratic Republic of Ethiopia (2011). *Ethiopia's Climate Resilient Green Economy (CRGE) Strategy.* Addis Ababa.

Federal Democratic Republic of Ethiopia (2017). *Nationally Determined Contribution.* https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Ethiopia%20First/INDC-Ethiopia-100615.pdf.

Ferede, T., Gebreegziabher, Z., Mekonnen, A., Guta, F. and Levin, J. (2015). *Biofuel Investments and Implications for the Environment in Ethiopia: An Economy-wide Analysis.* Environment for Development.

Gaia Association (2014). *Holistic Feasibility Study of a National Scale-up Program Regarding Bio-ethanol Stoves and Micro Distilleries.*

Gebreegziabher Z. and Mekonnen A. (2011). "Sustainable Financing of Ethiopia's Energy Infrastructure: An Economic Analysis." In: G. Alemu and W. Gebeyehu (eds.), Proceedings of the 9th International Conference on the Ethiopian Economy Volume II. Addis Ababa: Ethiopian Economics Association, pp. 155-176.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Gelagay, H.S. and Minale, A.S. (2016). Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. *International Soil and Water Conservation Research* 4, 126-136.

Guta, D.D. (2012). Application of an almost ideal demand system (AIDS) to Ethiopian rural residential energy use: Panel data evidence. *Energy Policy* 50, 528-539.

Guta, F., Damte, A. and Rede, T.F. (2015). The residential demand for electricity in Ethiopia. Environment for Development.

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A. *et al.* (2017). Comprehensive assessment of soil erosion risk for better land use planning in river basins: case study of the Upper Blue Nile River. *Science of the Total Environment*, 574: 95-108.

Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawm, T., Teferi, E. *et al.* (2015). Economics of Land Degradation (ELD) Ethiopia Case Study. Soil Degradation and Sustainable Land Management in the Rain-fed Agricultural Areas of Ethiopia: An Assessment of the Economic Implications. Report for the Economics of Land Degradation Initiative. 94.

International Energy Agency (2012). Energy balances of non-OECD countries. Paris.

International Energy Agency (2018). https://www.iea.org/countries/ethiopia/. Accessed 3 November 2018.

Knoema (2019). https://knoema.com/atlas/Ethiopia/topics/Energy/Renewables/Fuel-ethanol-production.

Matousa, P., Todob, Y. and Mojoc, D. (2013). Roles of extension and ethno-religious networks in acceptance of resource-conserving agriculture among Ethiopian farmers. *International Journal of Agricultural Sustainability* 11(4), 301-316.

Mekonnen, D., Bryan, E., Alemu, T. and Ringler, C. (2015). Food versus fuel: examining tradeoffs in the allocation of biomass energy sources to domestic and productive uses in Ethiopia. Agricultural and Applied Economics Association.

Mekonnen, M., Keesstra, S.D., Baartman, J.E., Ritsema, C.J. and Melesse, A.M. (2015). Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. *Cuadernos de Investigación Geográfica* 41, 16.

Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S. (2015). A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. *Renewable and Sustainable Energy Reviews* 48, 306-316.

Ministry of Environment, Forest and Climate Change (2016). *National Technology Needs Assessment for Climate Change Mitigation (Draft).* Addis Ababa.

Ministry of Environment, Forest and Climate Change and SNV Netherlands Development Organisation (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia*, Final Report Strengthening the Enabling Environment for Clean Cooking Project.

Ministry of Finance and Economic Development (2010). *The Five Years (2010/11-2014/15) Growth and Transformation Plan.* Addis Ababa.

Ministry of Mines and Energy (2007). *The Biofuel Development and Utilization Strategy of Ethiopia.* Addis Ababa.

Mondal, M.A.H., Bryan, E., Ringler, C., Mekonnen, D. and Rosegrant, M. (2018). Ethiopian energy status and demand scenarios: Prospects to improve energy efficiency and mitigate greenhouse gas (GHG) emissions. *Energy* 149, 161-172.

Mondal, M.A.H., Bryan, E., Ringler, C. and Rosegrant, M. (2017). Ethiopian power sector development: Renewable based universal electricity access and export strategies. *Renewable and Sustainable Energy Reviews* 75, 11-20.

Office for the Coordination of Human Affairs (2017). https://reliefweb.int/report/ethiopia/horn-africa-call-action-february-2017-enar.

RSB (2018). Event summary: A successful RSB Aviation Biofuel Summit in Ethiopia. https://rsb.org/2018/03/28/event-summary-a-successful-rsb-aviation-biofuel-summit-in-ethiopia/

Temesgen, M. (2018). *Financial and Economic Analysis of Ethanol Production from Sugar Molasses: A Case Study of an Integrated Sugar Plant in Ethiopia*.

United Nations International Children's Emergency Fund (2018). http://www.unicef.org/appeals/ethiopiaaccessed.

World Bank (2018). https://www.worldbank.org/en/country/ethiopia/overview. Accessed 2 November 2018.

Yewondwossen, M. (2018). Ethiopian ethanol production closer to reality. Capital Ethiopia. https://www.capitalethiopia.com/capital/ethiopian-ethanol-production-closer-realty.

3 DESCRIPTION OF THE SELECTED BIOENERGY PATHWAYS

3.1 The biogas pathway in Ethiopia

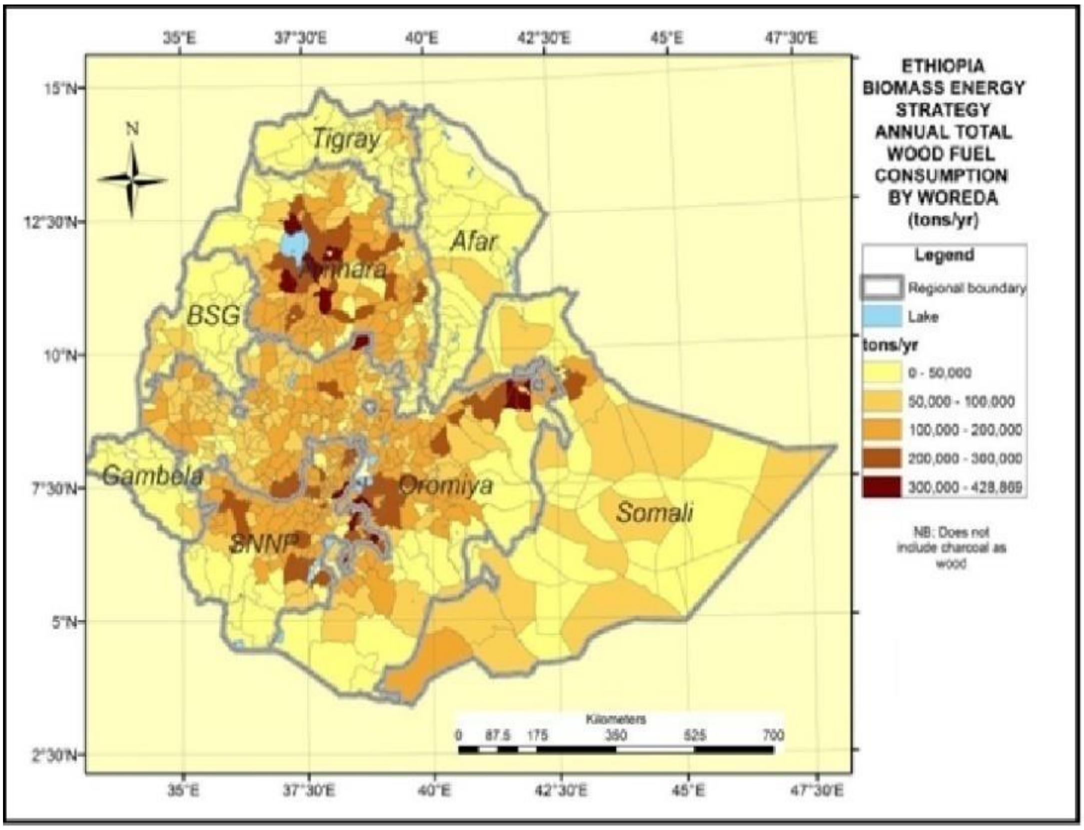
3.1.1 Supply and conversion

Main sources of biogas feedstock and potentials

Cattle
Ethiopia has a large livestock population. The country's livestock population according to the 2016/2017 survey was 59.5 million (Ethiopia Central Statistical Agency [CSA] 2017). Around 700 kilograms (kg) of dry dung can be obtained per animal per year (Bond and Templeton 2011). Cattle are mostly range fed, and around 40 per cent of the produced dung is not accessible for collection. Around 22.8 million tons of dung were used in Ethiopia in 2013 for energy purposes (Map 3.1).

The biogas yield of cow's dung is influenced by the type of feed and the digester's process conditions (Zinoviev *et al.* 2010). According to Seyoum (2018), around 2.83 cubic metres (m^3) of biogas can be produced per day by loading 45 kg of dung daily into a 6 m^3 SINIDU model biogas digester in Ethiopia. Biogas production also depends on the size of the biodigester (Table 3.1).

Map 3.1. Annual total dung consumption by wereda



Source: Geissler *et al.* 2013.

Table 3.1. Daily rate of feeding required livestock and estimated stove hours

Plant size (m^3)	Daily fresh dung (kg)		Daily water (L)		No. of cattle required		Min estimated gas production (L)		Min estimated stove hrs (400 L/h)	
	min	max	min	max	min	max	min	max	min	max
4	20	40	20	40	4	8	680	1 600	1.7	4.0
6	30	60	30	60	6	12	1 020	2 400	2.6	6.0
8	40	80	40	80	8	16	1 360	3 200	3.4	8.0
10	50	100	50	100	10	20	1 700	4 000	4.3	10.0

Source: Workneh and Eshete 2008.

Agricultural residues

Even if agricultural residues can be competitive biogas feedstocks sources in Ethiopia, biogas production from agricultural residues is not as popular as using cow dung in the country. Around 19.7 million tons per year of agricultural residues were used in Ethiopia in 2013 (Geissler *et al*. 2013). A biogas yield of 0.3-0.6 m^3/kg is mostly reported for cereal crop residues (Rajendran *et al.* 2012).

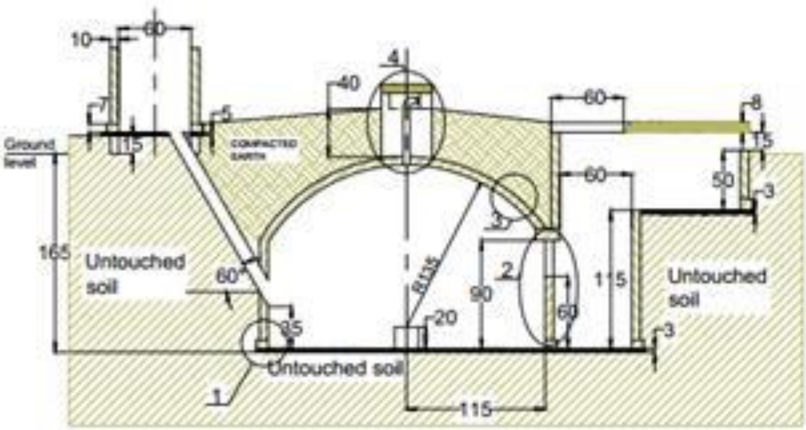
By-products of coffee processing, which are currently discarded as waste, could also be an alternative feedstock for biogas production in Ethiopia. The main regional states involved in coffee production and processing are Oromia; Southern Nations, Nationalities and Peoples' Region (SNNPR); and Gambella (Chala *et al.* 2018).

Types and capacity of digesters and stoves

The fixed-dome type of biodigester was selected by the National Bioenergy Programme of Ethiopia (NBPE) for promotion at the household scale (Workneh and Eshete 2008). It is a modified version of a Nepalese model with an Ethiopian name – SINIDU – with different sizes available between 4 m^3 and 10 m^3, of which 6 m^3 volume capacity is most common (Figure 3.1 and Table 3.2). This design is preferred because of its robustness, ease of operation, opportunity to accommodate high shares of local materials, correct sizing and low cost.

The use of biogas for cooking requires specially designed stoves. The thermal efficiency of such stoves is similar to that of LPG stoves, which is around 55-60 per cent (O'Sullivan and Barnes 2007).

Figure 3.1. Drawing of the SINIDU biogas digester



Source: Personal communication with Mr. Sisay Girma (NBPE).

Table 3.2. Capacity and number of biodigesters

Year	Capacity of biodigesters (m³)	Number of biodigesters	Year	Capacity of biodigesters (m³)	Number of biodigesters
	A	B		A	B
2015	4 m^3	2 588	2017	4 m^3	1 848
	6 m^3	10 091		6 m^3	15 893
	8 m^3	194		8 m^3	462
	10 m^3	65		10 m^3	277
	Total	12 938		Total	18 480
2016	4 m^3	2 324	2018	4 m^3	1 330
	6 m^3	12 702		6 m^3	19 728
	8 m^3	310		8 m^3	665
	10 m^3	155		10 m^3	443
	Total	15 491		Total	22 166

Source: Reports of National Biogas Programme of Ethiopia (Rai 2018; Seyoum 2018).

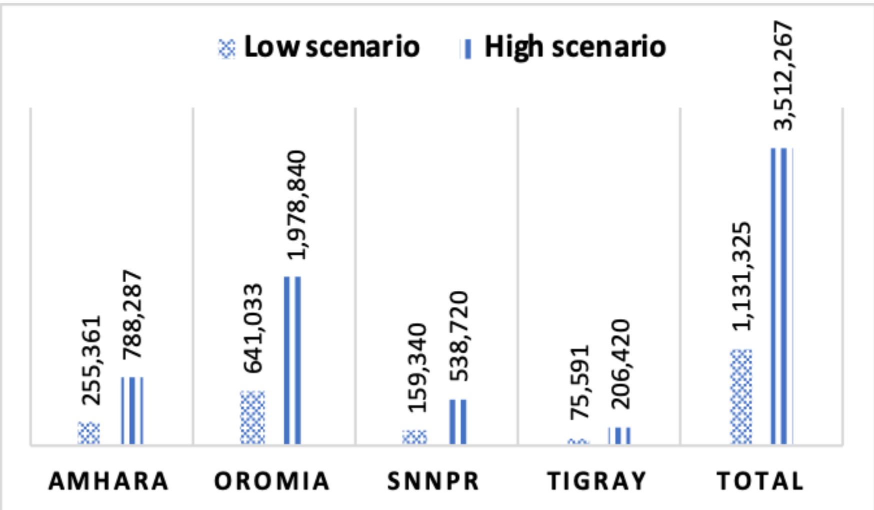
3.1.2 Policies and programmes applied to biogas pathway

Ethiopia has already prepared an energy policy to promote the utilization of bioenergy (Ministry of Water and Energy 2012). It also has a large National Biogas Programme, with three main phases.

The first stage (2008-2013)

A feasibility study undertaken by the Ethiopian Rural Energy Development and Promotion Centre (EREDPC) and SNV-Ethiopia in 2006 (Esthete, Sonder and ter Heegde 2006) assessed two scenarios of biogas production potential in Ethiopia, with the options of implementing from more than 1 million to 3.5 million digesters in four regions of Ethiopia (Figure 3.2).

Figure 3.2. Biogas potential (digesters) of some regions of Ethiopia



Based on this study, the National Biogas Programme of Ethiopia was launched for a first stage of implementation between 2008 and 2013 (Kamp and Forn 2016; Yitayal, Mekibib and Araya 2017). The plan was to build 14,000 family-sized biogas digesters (Table 3.3). The SINIDU model, an adaptation of the Nepalese GGC-2047 fixed-dome digester, was installed (Boers, Workneh and Eshete

2008). Most of the biogas digesters are fed with cow dung waste (Mengistu *et al*. 2015; Gwavuya *et al.* 2012).

Only 8,161 biogas digesters were built during the first phase of the National Biogas Programme (Table 3.3), including 2,480 biodigesters in Oromia, 1,992 in Tigray, 1,892 in Amhara and 1,699 in SNNPR (Alemayehu 2014). The first years of implementation of the programme faced several obstacles. Firstly, biogas was considered a new technology in the rural context. The situation was also exacerbated by a cement crisis facing the country during 2010-2011 (Alemayehu 2014). Another challenge was the limited availability of qualified masons to properly build the digesters. The availability of credit for households was also too limited despite the micro-finance arrangements put in place.

In 2010, during an intermediate revision of the National Biogas Programme, it was decided to reduce the initial target from 14,000 to 10,000 biogas digesters by the end of the first phase in 2013.

Table 3.3. Summary of biogas digesters installed during first phase of National Biogas Programme

<table>
<tr><td colspan="8">Targets/accomplishments</td></tr>
<tr><td colspan="5">Indicator</td><td colspan="2">Initial target</td><td>Actual implementation</td></tr>
<tr><td colspan="5">Number of constructed biogas digesters</td><td colspan="2">14 000</td><td>8 161</td></tr>
<tr><td colspan="5">Number of active woredas (districts)</td><td colspan="2">28</td><td>130</td></tr>
<tr><td colspan="5">Average cost of biodigester (6 m^3)</td><td colspan="2">7 519 birr</td><td>14 000 birr</td></tr>
<tr><td colspan="5">Percentage of cost covered by subsidy</td><td colspan="2">57%</td><td>43%</td></tr>
<tr><td colspan="8">Number of biogas digesters installed per year by National Biogas Programme phase 1</td></tr>
<tr><td></td><td>2008</td><td>2009</td><td>2010</td><td>2011</td><td>2012</td><td>2013</td><td>Sum</td></tr>
<tr><td>Forecast</td><td>100</td><td>400</td><td>1 000</td><td>2 000</td><td>3 000</td><td>3 500</td><td>10 000</td></tr>
<tr><td>Actual</td><td>98</td><td>30</td><td>731</td><td>1 641</td><td>2 511</td><td>3 150</td><td>8 161[(1)]</td></tr>
</table>

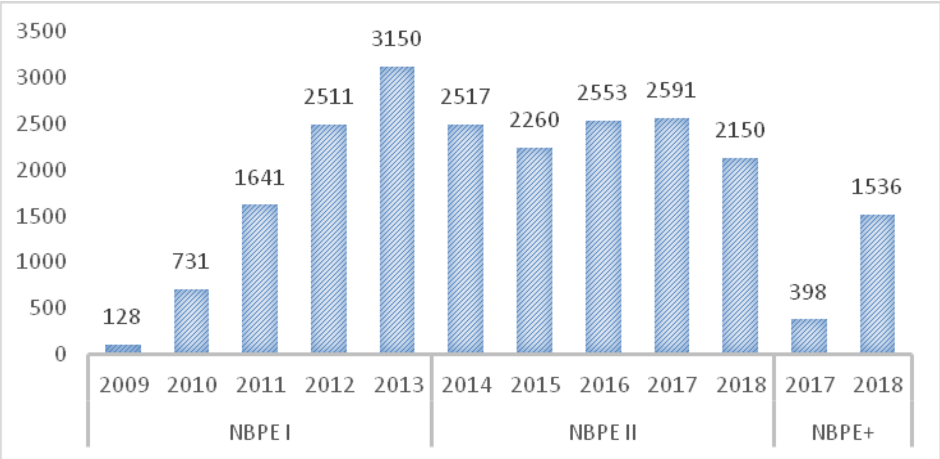
[(1)] 82% of the revised target or 58% of the original target
Source: Kamp and Forn 2016.

The second stage of the NBPE (2014-2017)

The second phase of the National Biogas Programme took place from 2014 to 2017 and aimed to construct 20,000 additional biogas digesters. According to Rai (2018), a total of 12,071 biogas digesters were built during the second phase (Figure 3.3).

A significant goal for this second phase was to enable private sector involvement in the production of biogas for consumption and business, a goal that was not accomplished in the first stage of the National Biogas Programme (Oppennoorth 2014). The private sector was also encouraged to construct biogas digesters domestically.

Figure 3.3. Yearly distribution of biogas digesters in Ethiopia



Data source: Rai 2018.

Current and future developments

The government wants to expand the production and utilization of biogas in the country. Financial support was obtained from the European Commission in 2016 to scale up the dissemination of the National Biogas Programme (NBPE+). The total cost of the project is 23,000,000 Euro of which 21,000,000 Euro is to be covered by the European Development Fund. It is being implemented within 60 months (2016-2020).

The objective is to improve the living standards of rural Ethiopians by promoting the use of clean and renewable biogas. Around 35,000 biogas digesters will be installed to impact 210,000 people in eight regions of Ethiopia (Afar, Amhara, Benishangul-Gumuz, Gambela, Oromia, SNNPR, Somali and Tigray regional states). The project will develop mechanisms and partnerships to ensure that a self-sustaining biogas market is created. Total number of installed biodigesters is therefore expected to have already increased!

The main implementers

Amongst the main NGOs working on biogas promotion in Ethiopia, LEM-Ethiopia and the Institute for Sustainable Development work respectively on biogas promotion and awareness and on user training on bioslurry utilization (Kamp and Forn 2016). Furthermore, SNV-Ethiopia plays a role as technical advisor and promoter of biodigester implementation.

3.1.3 Challenges and opportunities to biogas development

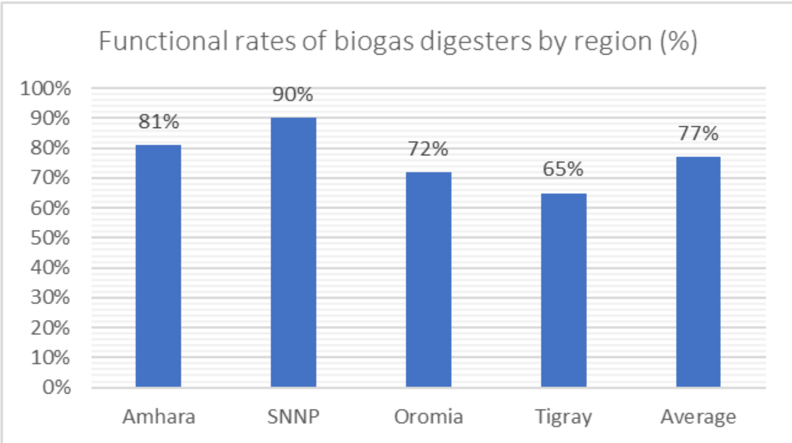
Expected benefits of biodigester development are numerous.

- *At the household level*: clean and renewable energy, health benefits, time saving, improved sanitary conditions, increased agricultural production, economic and financial returns. Women are particularly targeted, more particularly related to time savings and labour associated with the provision of energy for consumption.
- *At the national level*: reduction of the over exploitation of the biomass cover, rural employment, income generation, micro and small enterprise development.
- *At the global level:* reduction in greenhouse gas emissions.

Despite the promising impacts of biogas development, the implementation of a domestic biogas programme is not simple, and not all biodigesters are working (Figure 3.4). The main constraints are as follows: 1) low income of most rural households, 2) scarce availability of water, 3) scattered population pattern, 4) gender imbalance in decision making at the household level, and 5) low awareness of domestic biogas technology (Esthete, Sonder and ter Heegde 2006).

A significant challenge in many areas of Ethiopia is water scarcity and drought during certain times of the year. Under the traditional fixed-dome model, an equal amount of manure and water has to be provided daily. To remediate the scarcity of water in biogas digesters, 50 per cent of the digesters in Ethiopia are made to have a toilet connection (Jijawo 2014). However, this contribution is negligible in comparison to the daily amount of excreta or liquid that is required (Tauseef *et al*. 2013).

Figure 3.4. Functionality rate by region (%)



Source: Rai 2018.

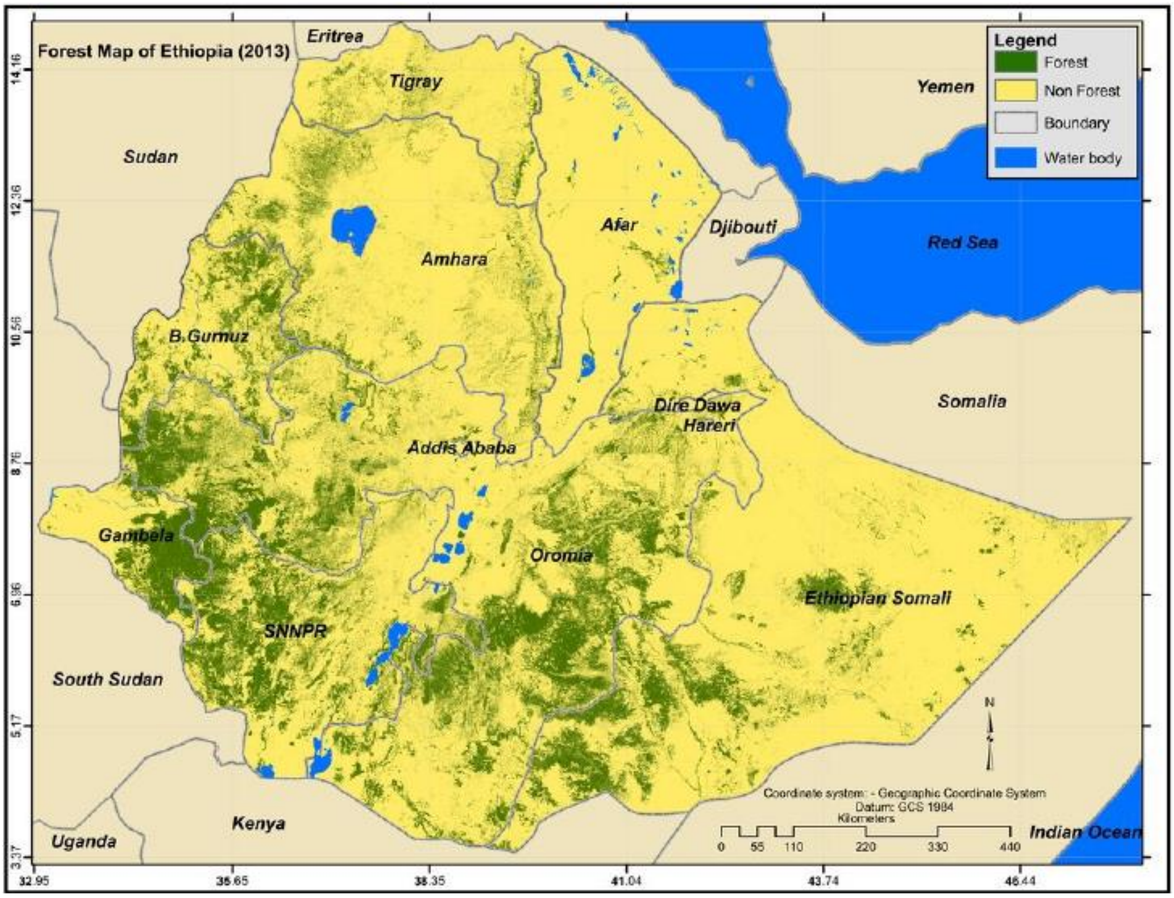
3.2 The solid biomass (fuel wood and charcoal) pathway

3.2.1 Supply

Forestry coverage

Different sources give differing figures for the forest cover of Ethiopia. While FAO estimates the Ethiopian forest cover to be around 11.4 per cent (Food and Agriculture Organization [FAO] 2015), Amente *et al.* (2016) claim it to be more than 15 per cent by adopting a new definition of forests. Map 3.2 shows a map of the forest cover of Ethiopia. More details are provided in the analysis of Indicator 3 on harvest levels of wood resources.

Map 3.2. Forest cover of Ethiopia



Source: National REDD+ Secretariat, MEFCC 2018.

Woody biomass

Biomass can be found in many forms, including forestry resources, agricultural crop and processing residues, dedicated energy crops such as miscanthus and switchgrass, and municipal solid waste (Hood *et al.* 2011). Although biomass can be used for diverse purposes, nearly 95 per cent of the nation's energy supply is derived from it; woody biomass is the most important biomass fuel, providing an estimated 68 per cent of the total (Berhanu *et al.* 2016; Ministry of Environment, Forest and Climate Change [MEFCC] 2018).

In Ethiopia, wood fuel is produced legally and sustainably from natural high forests and woodlands (27 per cent), area exclosures (1.4 per cent) and energy plantations and woodlots (5.5 per cent). A small volume of wood fuel is also sourced from wood waste (0.14 per cent) and a negligible amount from imports. The remainder, around 66 per cent, is unsustainably sourced from natural high forests and woodlands (Table 3.4). The biomass demand for fuel, with per capita consumption of around 0.9 tons per year, is double that of the sustainable annual yield. The forest sector review (MEFCC 2017) indicates that the volume of sustainable yields of branches, twigs and leaves from high forest is 3.4 million m^3, woodland 3.3 million m^3 and shrubland 2.0 million m^3.

Data from FAO (2018) indicate that the annual fuelwood (including wood for charcoal production) and charcoal production of Ethiopia were around 109,389,000 m^3 and 4,317,000 Mt, respectively.

Table 3.4. Categories of forests with their coverage, mean annual increment and yield

Category of forests	Sub-category	Coverage [mil. ha]	Mean annual increment [m³/ha/year]	Annual yield	
				[mil m³]	[mil tons]
Natural forest	High forest	2.9	5.65	10.5	7.6
	Woodland	21.5	0.8	11.1	8.0
	Shrubland	20.1	0.5	6.5	4.7
	Subtotal (Natural)	**44.5**		**28.1**	**20.4**
Plantation	Public plantations Oromia	0.0577	15.7	0.9	0.7
	Public plantations Amhara	0.0321	15.7	0.5	0.4
	Particleboard plantations	0.015	15.7	0.2	0.2
	Public plantations other regions	0.052	20	1	0.8
	Peri-urban energy plantations	0.0267	15	0.4	0.3
	Private/community small-scale woodlots	0.778	15	11.7	8.5
	Subtotal (manmade forests)	**0.9615**		**14.8**	**10.7**
All forests		**45.5**		**42.9**	**31.1**

Source: MEFCC 2017; MEFCC 2018.

Biomass of various sizes and shapes, including fine biomass, has been utilized. The fine biomass may be raw biomass or remnant dust from charcoal making. The fine biomass used to be left at production sites or dumped as waste. However, as population pressure increased, the rise in the demand for fuel was tremendous. As a result, the fine biomass was found to be useful either as fuel directly or after compaction through traditional or industrial means.

Agriculture and animal residues

In terms of energy potential, woody biomass accounts for around 79 per cent of the total biomass resource potential; animal waste represents 11 per cent, crop residues 8 per cent and human waste 2 per cent (Bewketu *et al.* 2014; MEFCC 2017).

Agricultural residues are important as a source of biomass intended for fuel (Table 3.5). The utilization rate of agricultural residues is low and accounts for only 30 per cent (MEFCC 2016; Berhanu *et al.* 2016).

Table 3.5. Agricultural production and residues

Type of crop	Residue	Land cover (1 000 ha)	2014/2015 Production (1 000 tons)	Residue-to-production ratio	Quantity of residue (1 000 tons)
Teff	Chaff	3 017.5	4 420.6	9	39 785.4
Wheat	Chaff	1 605.8	3 930.1	1.75	6 877.7
Maize	Stalk	2 027.19	6 497.5	2.11	13 709.7
Pulses	Chaff	1 732.6	2 820.8	1.89	5 331.3
Sugarcane leaf	Leaf	30.1	1 513.4	0.298	451.0
Sorghum	Stalk	1 678.4	3 720.8	2.23	8 297.4
Barley	Chaff	1 020.4	1 210.2	1.76	2 130.0
Vegetables residue		171.4	714.8	0.42	300.2
Sugarcane bagasse	Bagasse	30.1	1 513.4	0.36	544.8
Rice	Chaff	34.8	90.3	1.72	155.3
Coffee	Husk	598.4	372	2.11	784.9
Grass	Stalk/ Chaff	707			
P. Julifloa and other invasive bush	Biomass	502 400	21		21
Forest residue	Biomass	180 000			105
Cattle dung	Dung				23

Source: Berhanu *et al.* 2016; Tekleyohannes *et al.* 2018.

Supply by region

Table 3.6 presents the annual supply of woody biomass by region.

Table 3.6. Total biomass production by region

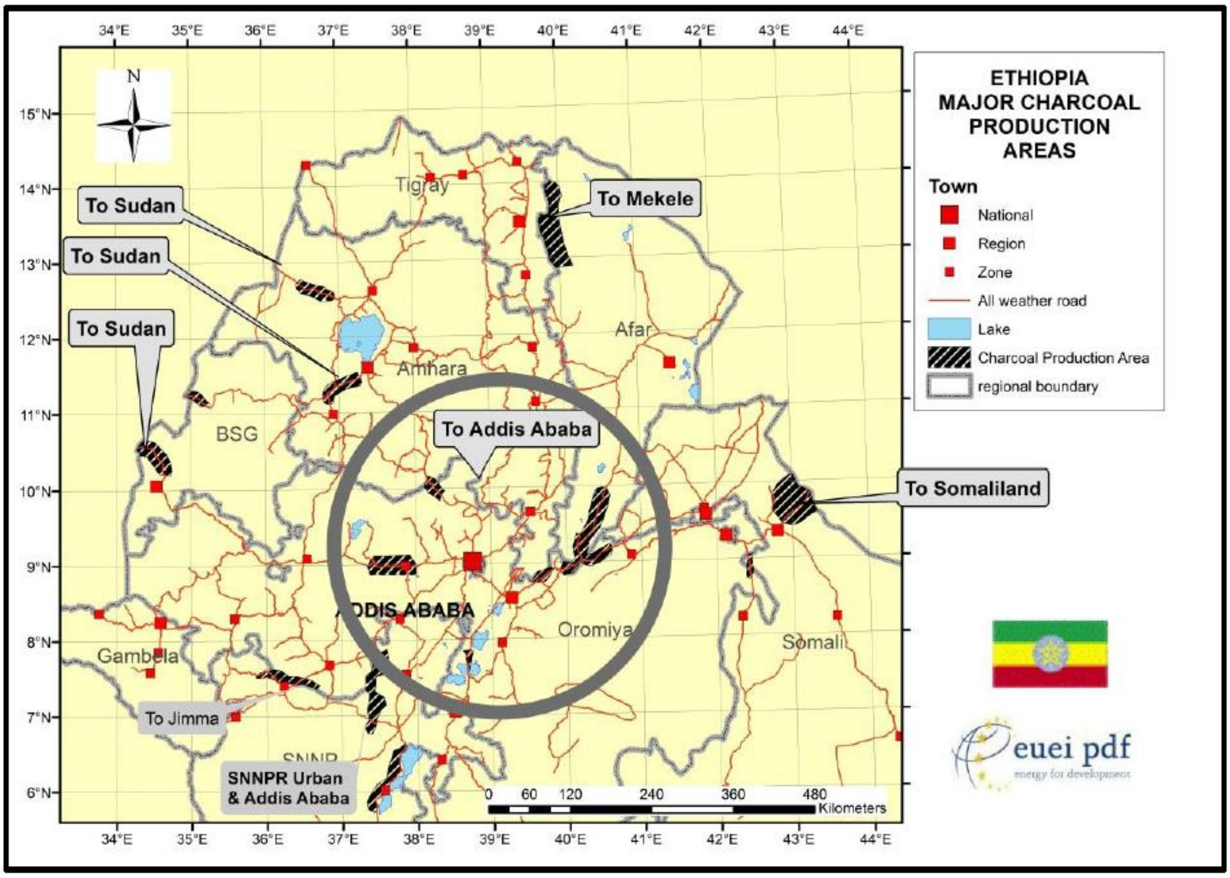
Region	Natural stock [tons]	Natural yield [tons/yr]	On-farm trees Stock [tons]	On-farm trees yield [tons/yr]	Total yield [tons/yr]	Branches, leaves and twigs [tons/yr]	Dead wood [tons/yr]	Wood clearing [tons/yr]	Sustainable yield [tons/yr]	Sustainable wood [tons/yr]
Addis Ababa	503 009	83 835			83 835	16 767			100 602	0.1
Afar	15 639 133	909 141			909 141	181 830	312 783		1 403 754	0.7
Amhara	111 210 009	5 870 207	296 872 394	26 718 515	32 588 722	1 987 401	2 224 203		36 800 326	18.7
BSG	76 613 747	3 529 603	7 648 653	688 379	4 217 982	705 920	1 532 275		6 456 177	3.3
Diredawa	565 621	34 427	2 943 252	264 895	299 322	7 240	11 313		317 875	0.2
Gambela	69 150 099	3 319 232	3 958 970	356 307	3 675 639	664 316	1 815 641		6 155 597	3.1
Harari	15 708	1 037	2 067 722	186 095	187 132				187 132	0.1
Oromiya	348 563 457	17 983 736	519 072 363	46 726 583	64 710 319	3 851 003	6 935 040	1 611 088	77 107 450	39.2
SNNPR	226 831 897	9 264 276	362 786 103	32 658 977	41 923 253	2 120 243	4 995 391		49 038 887	25
Somali	261 209 171	7 949 673	14 605 082	1 314 457	9 264 130	1 589 931	5 224 183		16 078 245	8.2
Tigrai	30 508 605	809 615	14 410 347	1 296 931	2 106 546	177 089	610 170		2 893 805	1.5
Total	1 140 810 456	49 754 882	1 224 364 885	110 211 141	159 966 022	11 301 740	23 660 999	1 611 088	196 539 850	

Source: Geissler *et al*. 2013.

Supply of charcoal
Male youth in rural areas manufacture charcoal – using inefficient (10-15 per cent) earth-mound kilns – from freely harvested acacia timber species (such as *Acacia tortilis*, *A. mellifera*, *A. Senegal* and *A. seyal*) in Gewane in Afar; in Bilate in SNNPR; in Langano and in Borana, Oromiya, and in the Harshin and Somale regions. The charcoal is supplied to nearby and distant towns and cities in each region and beyond. Charcoal also is produced in the dry woodlands of Amhara, Tigray and Benishangul-Gumuz. The bulk of charcoal comes from either acacia species and/or the invasive species *Prosopis juliflora* through the eastern gate to Addis Ababa. Map 3.3 shows the approximate locations of charcoal production in Ethiopia.

Charcoal production in Ethiopia, particularly from acacia woodland timber species, is illegal. As in the majority of sub-Saharan African countries, in Ethiopia the charcoal is produced, packed, transported and distributed to wholesalers or retailers without formal legalization and with law enforcement authorities turning a blind eye. Any of the actors can also sell charcoal to consumers directly (Bekele and Girmay 2013).

Map 3.3. Main locations of charcoal production



Source: Geissler *et al.* 2019.

Charcoal briquettes from bamboo, *Prosopis juliflora* and other biomass residues are being produced on a limited scale (Bekele and Girmay 2013; Emrich 1985). The same study shows that 42,045 sacks of charcoal were entering the city of Addis Ababa each day, which may translate to 537,124,875 tons per annum. Although charcoal making from *Eucalyptus camaldulensis* is being observed, acacia species remain favoured because of their smooth combustion and better energy yield.

Charcoal is dominantly produced in a traditional way using charcoal pits and earth-mound kilns, as shown in the past by Emrich (1985). It continues to be produced through traditional means (Figure 3.5). Some improved charcoal-making methods, such as using Casamance kilns, metal kilns and drum kilns, have been introduced and are being used at a limited scale. The conversion efficiency of traditional kilns is very low, in the range of only 10 to 15 per cent.

Figure 3.5. Earth-mound charcoal production

Source: Bekele and Girmay 2013.

Experience in participatory forest management

One of the sources of sustainable biomass supply are managed natural forests and exclosures. Managed natural forests are those tended by participatory community development activities, known as participatory forest management (PFM). PFM is exercised to reconcile conflicts of interest in a multi-stakeholder-based decision-making process with the objective of managing multi-purpose forest resources by establishing mechanisms to managing their excess (Limenih and Bekele 2008).

The seemingly successful PFM has mainly been supported by the German and Japanese development cooperation agencies, GIZ and JICA, respectively. The NGO Farm Africa has also been a player in PFM. While natural forests in general are closed for biomass extraction, those under the umbrella of PFM are open to utilization of forest excess without causing degradation, including for fuel when conditions allow. Although their share is not exactly known, in many parts of the country, mainly in Amhara and Tigray Regional States, some communal woodlands are closed for rehabilitation and conservation purposes and are not available to harvest fuelwood.

3.2.2 Consumption of biomass fuel

Overall consumption

Biomass is used in 90 to 92 per cent of Ethiopian households to obtain energy for cooking and heating (Bewketu *et al.* 2014). Households usually use a mix of biomass based on the agroecology system in which they are located and the type of biomass that is accessible to them (Table 3.7 and Table 3.8). Around 11 per cent of the total wood biomass is consumed in urban areas. Consumption is estimated at 0.917 tons per capita per year according to an unpublished project document of the former MEFCC in 2018. Consumption by restaurants and other food services in rural areas is 0.3 tons, by boarding schools and universities 0.75 tons and by day schools 0.26 tons.

Table 3.7. Total biomass fuel consumption by region

Region	Round wood [tons/yr]	Branches, leaves and twigs [tons/yr]	Charcoal as wood [tons/yr]	Total wood [tons/yr]	Total wood [%]	Residues [tons/yr]	Dung [tons/yr]	Charcoal [tons/yr]
Addis Ababa	684 228		1 060 439	1 744 667	2		39 964	212 088
Afar	830 552		1 195 154	2 025 706	2		49 364	239 031
Amhara	9 549 847	8 042 277	6 603 169	24 287 123	23	3 867 504	8 221 892	1 339 000
BSG	419 308	271 709	202 893	896 911	1	427 246	188 435	40 579
Diredawa	219 831	54 698	359 246	633 774	1	39 971	29 548	71 849
Gambela	181 653	74 736	96 236	364 659	0	67 069	44 966	20 735
Harari	136 728	38 463	225 685	400 876	0	28 108	21 501	45 137
Oromiya	17 812 299	11 070 636	9 921 703	38 804 638	37	7 571 451	6 261 813	1 984 341
SNNPR	15 264 304	7 185 536	3 564 630	26 014 470	25	7 539 192	2 229 843	712 926
Somali	2 520 644	211 155	3 203 569	5 935 369	6	152 929	220 755	614 467
Tigrai	614 995	1 284 533	2 167 743	4 067 271	4	31 256	5 511 309	433 549
Total	48 234 389	28 233 742	28 600 468	105 172 465		19 724 725	22 819 390	5 713 549

Source: Geissler *et al*. 2013.

Table 3.8. Source and type of fuel/ energy used by urban and rural households

Type of fuel	Percentage of households [%]			
	Country level	Rural	Small town (urban)	Large town urban
Collected firewood	61.5	77.2	34.6	14
Purchased firewood	12.1	3.2	46.7	33
Charcoal	5.2	0.5	6.4	21.7
Crop residue/leaves	6.8	8.9	0.7	1.3
Dung/manure	6.6	8.2	2.1	2
Electricity	5.2	0.1	4.5	23.3
None	0.9	0.3	2.3	2.8
Other	1.8	1.7	2.7	1.9

Source: CSA and World Bank 2017.

Cookstoves

Cookstoves are indispensable devices for the conversion of biomass to energy for cooking. Cookstoves can generally be classified and identified based on the level of applied engineering knowledge, material of construction, type of draft used, combustion, intended use (for domestic or communal purposes), functionality, presence of chimney, portability and type of feedstock used (Kshirsagar and Kalamkar 2014). In the traditional cooking method, a three-stone open cookstove is used with wood, and a stove made of sheet metal is used with charcoal. Open three-stone stoves dissipate most of the heat into the surroundings without any significant recovery. The traditional open-fire cookstove can be improved to a closed stove with either cement or clay enclosure and is 25 to 50 per cent more energy efficient, with less smoke and less carbon monoxide emission (Figure 3.9). The traditional charcoal stove is improved by incorporating a clay lining that enables more thermal heat retention and less radial heat dissipation (Figure 3.10).

Biomass cookstoves can be generally categorized as those for injera baking (Mirt and Gonzye stoves) and those for pot-size general cooking (mainly Tikikil) (Figure 3.6). Typical charcoal cookstoves include Merchaye, Lakech and traditional metal stoves (Figure 3.7). They are also categorized as charcoal stoves (e.g., Lakech and Mirchaye) and wood/raw biomass (Tikikil and all injera baking) according to the fuel they use. Of the improved stoves implemented from 2005 to 2017, 27 per cent were closed mud stoves, 21 per cent Mirt stoves, 14 per cent Lakech, 6 per cent Tikikil, 5 per cent Upesi and 1 per cent other stoves (Energypedia 2018).

The metal traditional charcoal cookstove needs 700 grams (g) of charcoal to meet the daily cooking energy demand of an average household, while Mirchaye and Lakech stoves need only 478 g and 536 g of charcoal for the same purpose (Mamuye *et al*. 2017).

While the Lakech improved cookstove has been more popular than the Mirchaye, the latter is gaining in popularity. Nevertheless, there is still a need to cover around 80 per cent of the households that still do not use yet the improved cookstove (Table 3.9).

Table 3.9. Distribution of improved cookstoves by Ethiopian government and GIZ

Region	2011	2012	2013	2014	2015	2016	2017	Sum
Oromiya	529 744	613 245	1 491 263	892 861	886 082	685 259	707 139	5 805 593
Amhara	598 747	419 831	80 769	93 583	104 879	255 256	205 736	1 758 801
SNNPR	106 366	124 616	122 374	135 457	80 485	133 439	124 401	827 138
Tigrai	16 488	34 420	0	82 605	103 789	140 517	130 413	508 232
Benshangul-Gumaz	5 685	2 895	2 971	4 170	2 809	7 993	10 615	37 138
Dire Dawa	800	4654			538	3 200	13 741	22 933
Somale	113	35				1 500	1 500	3 148
Afar						1 523	3 500	5 023
Harari						4 682	600	5 282
Gambela						424		424
Addis Ababa	60 885	199 147	182 498	383 183	223 470	373 149	296 500	1 718 832
GIZ		85 585	124 325	95 661	112 377			417 948
Total	1 318 828	1 484 428	2 004 200	1 687 520	1 514 429	1 606 942	1 494 145	11 110 492

Source: Unpublished data obtained from Water, Irrigation and Energy 2018.

Figure 3.6. Injera baking biomass improved cookstoves available in Ethiopia

Left side - Mirt (Tier 0: Fuel use: 393 g/kg)
Middle - Gonzye (Tier 0: Fuel use: 617 g/kg)
Right side - biomass pot-size cookstove named Tikikil (Tier 2: Thermal efficiency: 26%)

Source: MEFCC and SNV 2018.

Figure 3.7. Charcoal improved cookstoves

Left side – Mirchaye (7.5 L water /478 g of charcoal / day)
Middle – Laketch (7.5 L water / 536 g of charcoal/ day)
Right side - tradition metal cookstove (7.5 L water / 700 g of charcoal/ day)

Source: Mamuye *et al.* 2017.

Table 3.10. Performance-based categorization of cookstoves

Tier	Emissions				Efficiency / Fuel use		Indoor emissions		Safety
	High power CO		Lower power PM		High power	Lower power			
	[g/MJ]	[mg/MJ]	[g/min/L]	[mg/min/L]	Thermal efficiency [%]	Specific consumption [MJ/min/L]	CO [g/min]	PM [mg/min]	
0	>16	>979	>0.20	>8	<15	>0.050	>0.97	> 40	< 45
1	< 16	< 979	< 0.20	< 8	> 15	< 0.050	< 0.97	< 40	> 45
2	< 11	< 386	< 0.13	< 4	> 25	< 0.039	< 0.62	< 17	> 75
3	< 9	< 168	< 0.10	< 2	> 35	< 0.028	< 0.49	< 8	> 88
4	< 8	< 41	< 0.09	< 1	> 45	< 0.017	< 0.42	< 2	> 95

Source: MEFCC and SNV 2018.

3.2.3 Projects, programmes and policies

Policies

The draft national energy policy of 2013 is yet to be endorsed by the Council of Ministers. Clean cooking and bioenergy policies include the promotion of clean and efficient technologies, particularly for the household sector; and sustainable bioenergy production.

The Biomass Energy Strategy (BEST), issued in 2013, proposed increasing the biomass energy supply base through the promotion of fast-growing trees, increasing biomass fuel use efficiencies, and integration of the BEST strategy into energy policy and a special policy on charcoal.

The government established the National Improved Cookstoves Program (NICSP) in 2013, to run up to 2030 with five-year phases aligned with the government's Growth and Transformation Plan (GTP). The main objective of the programme is to support the government's GTP targets for improved cookstove adoption and dissemination by creating a vibrant market for improved cookstove technologies through relevant institutional capacity development and strong support of private sector involvement. It will also contribute to realization of the Climate Resilient Green Growth strategy of reducing emissions from deforestation and forest degradation and ensuring access to clean energy.

By coordinating all the stakeholders, the programme aims to empower the private sector to grow in all aspects of the value chain and to develop the improved cookstove market where customer demand "pulls" products through the value chain as opposed to the government "pushing" products to customers. The target for GTP-I period (2011-2015) was to distribute around 9.415 million improved cookstoves; distribution of more than 8.87 million of the stoves was achieved. By the year 2017, more than 15 million improved cookstoves were already disseminated (MEFCC 2017). A target of 11.45 million is set for GTP-II period (2016-2020), taking into account the lessons learned from the first period.

Equally importantly, biomass energy is also part of the country's mix of sustainable or renewable energy sources (MEFCC 2016). In this regard, tree planting on farms and as home gardens is being promoted to encourage the sustainable use of biomass as a cost-effective household fuel (Gebreegziabher and van Kooten 2013).

The availability and sustainable use of biomass resources will be supported by the country's national forest monitoring system, which will maintain updated forest statistics at the national and sub-regional/regional scales (MEFCC 2017). This has been a severe constraint for evidence-based decision making in the forest biomass-using energy sector. The government has also devised a financial and granting facility (CRGE) under the major supervision of the Ethiopian Environment, Forest and Climate Change Commission. The Facility coordinates and supports projects aimed at efficient, sustainable and cost-effective use of biomass energy.

National standards

The Ethiopian Standard Agency has revised and developed the Clean Cook Stove and Clean Cooking Solution, Performance Requirements and Test Methods (ES 6085: 2019) document, based on the previous standard of 2017.

Some implementers

Finally, several projects are supported by NGOs. For example, GIZ has been supporting projects using the Mirt and Lakech brands of biomass cookstoves (GIZ ECO 2014). World Vision Ethiopia has been working with GIZ to disseminate biomass stoves to rural areas under broad programmes like the voluntary carbon market and the Clean Development Mechanism (CDM). Ethiopia is involved in several projects and programmes of activities under the CDM. Those are only examples. Many training activities by different partners were also implemented; more details are provided in Indicator 21.

3.2.4 Challenges and opportunities

Improved cookstoves have been undergoing continuous improvement and sometimes have acquired different brand names. Use of traditional cookstoves, which have poor combustion features, have very negative health impacts on vulnerable members of families such as children under the age of five, resulting in a high incidence of respiratory problems (Sanbata *et al.* 2014).

Beyond technical improvement of the stoves, it is important to pay attention to the determinants of adoption of newly improved cookstoves. Adoption of improved cookstoves was found to be largely influenced by the household head's age, sex, education level, income and wealth (Woubshet 2008; Beyene and Koch 2013; Mamuye *et al.* 2017).

A large proportion of the population still cooks with traditional stoves. The need to disseminate improved cookstoves and other clean cooking methods is therefore enormous.

3.3 References

BIOGAS

Alemayehu, T. (2014). Interview with Tesfaye Alemayehu, Chief Engineer at the NBPE. April 30, 2014. Addis Ababa.

Boers, W., Workneh, K. and Eshete, G. (2008). National Biogas Programme of Ethiopia Programme Implementation Document. Ethiopia Rural Energy Development and Promotion Centre (EREDPC)/ SNV/Ethiopia.

Bond, T. and Templeton, M.R. (2011). History and future of domestic biogas plants in the developing world. *Energy Sustain Dev.* 15, 347-54. http://dx.doi.org/10.1016/j.esd.2011.09.003.

Chala, B., Oechsner, H., Latif, S. and Müller, J. (2018). Biogas potential of coffee processing waste in Ethiopia. *Sustainability* 10, 2678. doi:10.3390/su10082678.

Esthete, G., Sonder, K. and ter Heegde, F. (2006). *Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia*. Addis Ababa.

Ethiopia Central Statistical Agency (2017). Agricultural Sample Survey 2016/17 [2009E.C.] Volume II, Report on livestock and livestock characteristics (private peasant holdings). Statistical Bulletin 585. Addis Ababa.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Gwavuya, S.G., Abele, S., Barfuss, I., Zeller, M. and Müller, J. (2012). Household energy economics in rural Ethiopia: A cost-benefit analysis of biogas energy. *Renew. Energy* 48, 202-209.

Jijawo, T. (2014). Interview with Tamirat Jijawo, Regional Biogas Coordinator for SNNPR. May 12, 2014.

Kamp, L.M. and Forn, E. (2016). Ethiopia's emerging domestic biogas sector: Current status, bottlenecks and drivers. *Renewable and Sustainable Energy Reviews* 60, 475-488. doi: 10.1016/j.rser.2016.01.068.

Kellner, C. (2014). Interview with Christopher Kellner, Regional Technical Advisor at BORDA. April 22, 2014.

Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S. (2015). A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. *Renewable and Sustainable Energy Reviews* 48, 306-316.

Ministry of Water and Energy (2012). *Ethiopian National Energy Policy*. Addis Ababa.

O'Sullivan, K. and Barnes, D.F. (2007). *Energy Policies and Multitopic Household Surveys: Guidelines for Questionnaire Design in Living Standards Measurement Studies*. World Bank Publications: Washington, DC.

Oppenoorth, H. (2014). Interview with Harrie Oppenoorth, Senior Advisor in Energy and Climate Change for Hivos International. April 17, 2014.

Rai, S. (2018). National Biogas Programme of Ethiopia (NBPE). Addis Ababa.

Rajendran, K., Aslanzadeh, S. and Taherzadeh, M.J. (2012). Household biogas digesters – A review. *Energies* 5, 2911-2942.

Seyoum, S. (2018). *The Economics of a Biogas Digester.* Livestock Economics Division ILCA, Addis Ababa. https://core.ac.uk/download/pdf/132634928.pdf.

Tauseef, S.M., Premalatha, M., Abbasi, T. and Abbasi, S. A. (2013). Methane capture from livestock manure. *Journal of Environmental Management* 117, 187-207. doi:10.1016/j.jenvman.2012.12.022.

Workneh, K. and Eshete, G. (2008). National Biogas Programme Ethiopia, programme implementation document. Ethiopian Rural Energy Development and Promotion Centre.

Yitayal, A., Mekibib D. and Araya A. (2017). Study on biogas production potential of leaves of Justicia schimperiana and macro-nutrients on the slurry. *Int J Waste Resour* 7, 294. doi: 10.4172/2252-5211.1000294.

Zinoviev, S., Müller-Langer, F., Das, P., Bertero, N., Fornasiero, P., Kaltschmitt, M. *et al.* (2010). Next-generation biofuels: Survey of emerging technologies and sustainability issues. *ChemSusChem* 3, 1106-1133.

SOLID BIOMASS

Amente, G., Tennigkeit, T., Carodenuto, S., Kassaye, M.L., Feye, T.A., Belay, H.K. *et al.* (2016). *National Forest Sector Development Programme, Institutional Strengthening for Forest Sector Development in Ethiopia*. United Nations Development Programme.

Bekele, M. and Girmay, Z. (2013). *Reading Through the Charcoal Industry in Ethiopia*. Addis Ababa.

Berhanu, M., Jabasingh, S.A. and Kifile, Z. (2016). Expanding sustenance in Ethiopia based on renewable energy resources – A comprehensive review. *Renewable and Sustainable Energy* 75, 1035-1045. doi:10.1016/j.rser.2016.11.082

Bewket, W., Gebreyohannis, S., Ayana, M., Adinew, M., Arega, T., Birru, B. *et al*. (2014). *First Assessment Report, Working Group II - Climate Change Impact, Vulnerability, Adaptation and Mitigation*, IV, Water and Energy, Ethiopian Academy of Sciences, Addis Ababa.

Beyene, A.D. and Koch S.F. (2013). Clean fuel-saving technology adoption in urban Ethiopia, *Energy Economics* 36, 605-613

Demissew, S., Woldu, Z., Bekele, T., Argaw, N., Ebissa, G., Abebe, K. *et al*. (2015). *Strategic Environmental and Social Assessment (SESA) For the Implementation of REDD+ in Ethiopia Including the Oromia Forested Landscape Program (OFLP) Social Assessment (SA)*. Ministry of Environment and Forest, The National REDD+ Secretariat and Oromia REDD+ Coordination Unit. Addis Ababa.

Emrich, W. (1985). *Energy from Biomass Handbook of Charcoal Making. The Traditional and Industrial Methods, Solar Energy R&D in the European Community*, Series E Vol 7.

Ethiopia Central Statistical Agency and World Bank (2017). *LSMS – Integrated Surveys on Agriculture – Ethiopia Socioeconomic Survey (ESS)2015/2016*. Central Statistical Agency and Living Standards Measurement Study (LSMS). World Bank. Addis Ababa.

Ethiopia National REDD+ Secretariat (2018). *National REDD+ Strategy (2018-2030). Federal Democratic Republic of Ethiopia*, Ministry of Environment, Forest and Climate Change, Addis Ababa, Ethiopia.

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

Food and Agriculture Organization of the United Nations (2018). *Forest Products 2016 Year Book*. FAO Statistics. Rome.

Gaia Association (2012). *Improved Cook Stoves, Final Report, GHG Mitigation and Sustainable Development through the Promotion of Energy Efficient Cooking in Social Institutions in Ethiopia*, Project implemented by

Gaia Consulting Oy and Ethio Resource Group. Financed by Nordic Climate Facility of Nordic Development Fund and the implementing partners.

Gebreegziabher, Z. and van Kooten G.C. (2013). Does community and household tree planting imply increased use of wood for fuel? Evidence from Ethiopia. *Policy and Economics* 34, 30-40.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

GIZ Energy Coordination Office GIZ-ECO (2014). *Energizing Development (EnDev) Ethiopia Improved Cook Stoves (ICS)*. Addis Ababa.

Hood, E.E., Nelson, P. and Powell, R. (2011). *Plant Biomass Conversion*. John Wiley & Sons.

Kilawe, E. and Habimana, D. (2016) *Forestry Contribution to National Economy and Trade in Ethiopia, Kenya and Uganda*. Food and Agriculture Organization of the United Nations. Addis Ababa.

Kshirsagar, M.P. and Kalamkar, V.R. (2014). A comprehensive review on biomass cookstoves and a systematic Approach for modern cookstove design. *Renewable and Sustainable Energy Reviews* 30, 580-603.

Lemenih, M. and Bekele, M. (2008). *Participatory Forest Management: Best Practices, Lesson Learnt and Challenges Encountered, The Ethiopian and Tanzanian Experiences*. FARM-Africa/SOS-Sahel.

Mamuye. F., Lemma, B. and Woldeamanuel, T. (2018). Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia, *Sustainable Environment Research* 28, 32-38.

Ministry of Environment, Forest and Climate Change (2016). *National Technology Needs Assessment for Climate Change Mitigation (Draft)*. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2017). *Ethiopia's Institutional Framework for the MRV under the REDD+ Program*. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Program, Ethiopia*. *Vol I. Situation Analysis.* Addis Ababa.

Ministry of Environment and Climate Change and SNV Netherlands Development Organisation (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia. Strengthening the Enabling Environment for Clean Cooking Project*, Final Report. Addis Ababa.

Sanbata, H., Asfaw, A. and Kumie, A. (2014). Association of biomass fuel use with acute respiratory infections among under- five children in a slum urban of Addis Ababa, Ethiopia, *BMC Public Health* 14, 1122.

Tekleyohannes, A., Tekola, B., Weldesenbet, F., Gonfa, G., Alemu, M. and Feleke, S. (2018). *Biomass Refinery of Ethiopia (Draft)*. Ethiopian Agricultural Research Council. Addis Ababa.

Woubishet, D. (2008). Fuel efficient technology adoption in Ethiopia: Evidence from improved “Mirt” stove technology: A case in selected kebeles from “Adea” Wereda. *Ethiopian Journal of Economics* XVII, 2.

4 RESULTS OF THE GBEP SUSTAINABILITY INDICATORS FOR BIOGAS AND SOLID BIOMASS FOR COOKING IN ETHIOPIA

4.1 Indicator 1. Life cycle greenhouse gas emissions

4.1.1 Researcher(s)

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4.1.2 Definition

(1.1) Lifecycle greenhouse gas emissions from bioenergy production and use, as per the methodology chosen nationally or at community level and reported using the GBEP Common Methodological Framework for GHG Lifecycle Analysis of Bioenergy Version One.

4.1.3 Measurement unit(s)

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

4.1.4 Overall methodology of the implementation

The spreadsheet-based life cycle analysis (LCA) tool, developed by the Institut Für Energie-und Umweltforschung Heidelberg (IFEU) in partnership with GBEP and UNEP, was used to quantify the carbon dioxide (CO_2), methane, and nitrous oxide emissions of each stage of the value chain: feedstock production and collection, processing, transport of primary or transformed resources, storage, and final uses by the consumers. The aggregation to CO_2 equivalent (CO_2eq) using the global warming potential (GWP) factors. Emission factors are based on international literature and life cycle analysis databases and adapted to Ethiopia.

Sources of information for the biogas pathway were secondary data, such as peer reviewed publications and reports of the National Biogas Programme and the Netherlands Development Organisation (SNV), locally working on biogas fuel development in Ethiopia. Emissions of the biogas pathway are then compared to those of a pathway based on traditional biomass (open fires).

Sources of information for the solid biomass pathway were secondary data, such as peer reviewed publications and data from the former Ministry of Environment, Forest and Climate Change of Ethiopia related to its cookstove project. The analysis considers the use of wood and charcoal in improved cookstoves. Emissions are compared to those of a pathway based on traditional biomass (open fires) and those of a pathway based on LPG. This comparison aims at exploring the consequences of fuel substitutions.

4.1.5 Key findings

BIOGAS

Assumptions
The National Biogas Programme (NBPE) uses standardized digesters serving individual households, which need to have at least four cattle so as to obtain adequate amount of excreta for effective anerobic digestion. The biogas is used without any upgrade. The digestate is either directly applied to fields or composted and then used for the same purpose. Therefore, the scope of life cycle

analysis of greenhouse gas emissions included the collection of the animals' excreta, the anaerobic digestion and the use of the biogas for cooking. It does not include the emissions associated with the bioslurry.

Main assumptions of the computation are presented in Table 4.1.

Table 4.1. Assumptions of the greenhouse gas life cycle analysis of the biogas pathway

Biogas	
Dung	No mechanical collection No transport 80% water content
Biodigester	No heating No electricity needed 0.04 m^3 biogas/kg fresh matter 60% methane content in volume
Methane leakage	1%
Cookstove thermal efficiency	57%
Reference case – traditional cooking solution (open fires)	
Biomass	No mechanical collection or logging No transport
Cookstove thermal efficiency	8%

Source: Assumptions on biogas are based on Tumwesige *et al*. 2014.

Share between supply, process and use

Greenhouse gas emissions from biogas are about 11.6 gCO_2eq per megajoule of energy produced at the utilization level. More than 90 per cent the greenhouse gas emissions from biogas come from the processing stage of the life cycle (Table 4.2), corresponding to leakage of 9.8 g of biogenic methane from the biodigester. The use of biogas for cooking generates only 9.3 per cent of total greenhouse gas emissions, composed of 5.1 per cent biogenic CO_2 and 4.2 per cent nitrous oxide in gCO_2eq.

Comparison with traditional cooking

Total emissions from biogas represent less than 4 per cent of emissions from traditional cooking systems based on open fires. This reduction corresponds to the emissions from burning during the cooking activity, which is less complete with firewood than with biogas.

Figure 4.1. Summary of life cycle greenhouse gas emissions from using biogas compared to traditional wood (open fires) for cooking

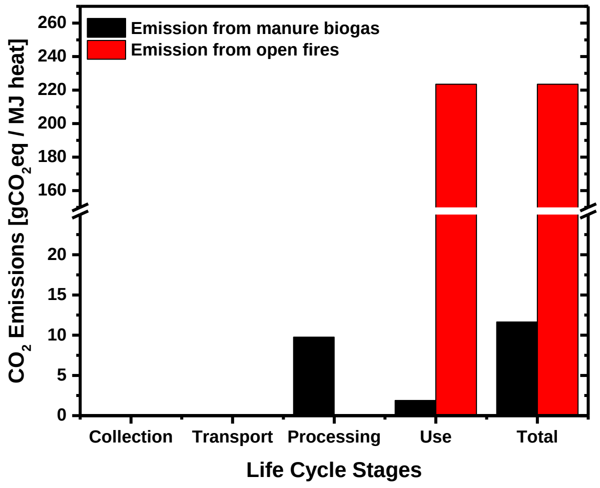

Table 4.2. Summary of life cycle greenhouse gas emissions from biogas compared to traditional wood (open fires)

Emission	Life cycle stage	Emission from manure biogas (gCO_2eq / MJ heat)	Reference emission from traditional wood fuel (gCO_2eq / MJ heat)	Difference in emissions (biogas over traditional wood cookstoves)	
				In percent (%)	Per functional unit (g CO_2eq / MJ heat)
CO_2 eq.	Collection	0	0	-	-
	Transport	0	0	-	-
	Processing	9.76	0	-	+9.76
	Use	1.88	223.51	-99	-221.63
	Total	11.64	223.51	-95	-211.87

FIREWOOD

Assumptions

The assumptions (Table 4.3) reflect the current situation related to the production, transport and use of firewood and charcoal. Solid wood biomass and charcoal come from both plantations/woodlots and natural forests. The analysis does not consider seed collection, nursery and trees/plantation management owing to absence of data.

Table 4.3. Assumptions of the greenhouse gas life cycle analysis of the solid biomass pathway

Wood used in improved cookstoves	
Wood	No mechanical collection or logging 72% water content
Transport	0 km to rural households 70 km to urban households, by platform truck (12 tons diesel)
Share wood consumed in urban areas	11%
Drying	Air drying 20% water content after drying
Cookstove thermal efficiency	28% thermal efficiency
Charcoal used in improved cookstoves	
Wood	No mechanical effort for collection 72% water content
Drying	Air drying 20% water content after drying
Kilns	Traditional kilns: 100%, with a conversion efficiency of 17% Modern kilns: 0%, with a conversion efficiency of 26%
Transport to kilns	To kilns: 5 km, by diesel platform truck From kilns to households: 200 km, by diesel platform truck
Share of cookstoves	Mirchaye (improved): 9% Lakech (improved): 11% Traditional: 80%
Cookstove thermal efficiency	Improved: 38% Traditional: 10%
Reference case – Traditional cooking solution (open fires)	
Biomass	No mechanical collection or logging Same transport distance as for wood or charcoal
Cookstove	8%
Reference case – LPG	
Thermal efficiency of stoves	54%
Transport of LPG by land	870 km
Transport vehicle for LPG	Tanker truck – medium
Transport of LPG by sea	1 884 km
Transport tanker, ship	Tanker ship – 22.56 kt

Source: Assumptions are made based on Bhattacharya *et al.* 2002; Hansmann *et al.* 2008; Chidumayo and Gumbo 2013; GEMIS 2014; Daniel 2016; Mamuye *et al*. 2017; SNV-SEECCS 2018; Ministry of Environment, Forest and Climate Change [MEFCC] 2019. Transport distances of LPG are obtained from shipping and road route as described in Google Maps.

Share between supply, process and use

The greenhouse gas emissions from production and use of firewood in improved cookstoves reaches 62 gCO_2eq per megajoule of heat generated (Table 4.5). Combustion at the stove level represents 95 per cent of the emissions. The key drivers behind the emissions are the efficiency of the improved cookstoves and the distance travelled between wood gathering and consumption.

Comparison with traditional wood (open fires) and improved cookstoves

The production and use of firewood in open fires needed to produce the same amount of energy to the same households would be about 234 gCO_{2eq} per megajoule of heat (Table 4.4). The fuel use generates most of the greenhouse gas emissions (Figure 4.2). The emission from the traditional biomass cooking solution (open fires) is higher by 60 per cent than that of the biomass improved cookstove. The difference comes mostly from the use, reflecting the higher efficiency of the improved cookstove compared to open fires (Figure 4.2, Table 4.4). Similarly, Figure 4.2 and Table 4.4 show the better performance of biomass improved cookstoves even when they are compared with LPG cookstoves, as the latter emitted 64 per cent more greenhouse gas emissions. The difference here is due to LPG processing and use.

Figure 4.2. Summary of life cycle greenhouse gas emissions from wood used in improved cookstoves compared to traditional wood (open fires) and LPG

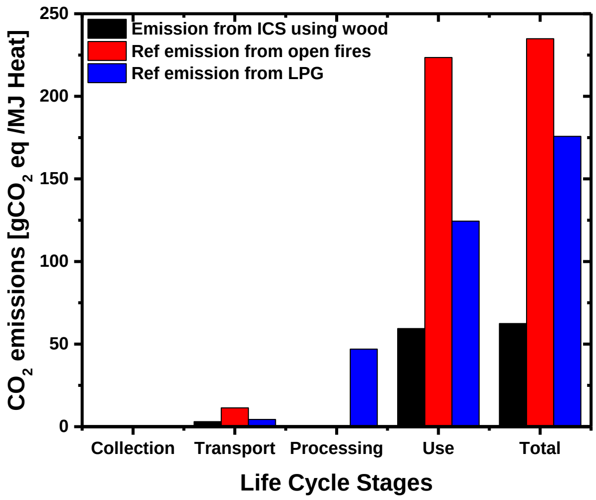

Table 4.4. Summary of life cycle greenhouse gas emissions from firewood used in improved cookstoves compared to traditional biomass cookstoves and LPG

Emission	Life cycle stages	Emission from ICS using wood (gCO_2eq / MJ heat)	Reference emission from open fires (gCO_2eq / MJ heat)	Reference emission from LPG (gCO_2eq / MJ heat)	Difference in emissions (wood ICS over open fires)		Difference in emissions (wood ICS over LPG)	
					In percent (%)	Per functional unit (gCO_2eq / MJ heat)	In percent (%)	Per functional unit (gCO_2eq / MJ heat)
CO_2eq	Collection	0	0	0	-	-	-	-
	Transport	3.04	11.35	8.56	-73	-8.31	-64	-5.52
	Processing	0	0.00	46.97	-	-	-100	-46.97
	Use	59.37	223.51	124.40	-73	-164.14	-52	-65.03
	Total	62.41	234.85	175.76	-73	-172.45	-64	-113.35

Note: ICS = improved cookstoves

CHARCOAL

Assumptions

Assumptions are described in Table 4.3.

Share between supply, process and use

The production and use of charcoal in improved cookstoves emit 130 g of greenhouse gas per mega joule of heat generated. The processing stage of charcoal emits 85 per cent of the total emission in the supply, processing and use.

Comparison with traditional wood and LPG

In a life cycle perspective, cooking with a charcoal improved cookstove emits 47 per cent less greenhouse gas than cooking with open fires, and 27 per cent less than cooking with LPG (Table 4.5). In all cases, the processing and use stages are the most emitting. More than 90 per cent of the emission of cooking with traditional wood (open fires) come from direct emission of burning; this is higher than in the case of charcoal and improved cookstoves due to the very low thermal efficiency of open fires. However, in the case of open fires, no emissions are emitted during processing, contrary to charcoal. More than 70 per cent percent of the emission from LPG comes from direct burning, because LPG is a fossil fuel. Emissions from processing LPG are smaller than emissions from processing charcoal.

Figure 4.3. Summary of life cycle greenhouse gas emissions from charcoal used in improved cookstoves compared to traditional wood (open fires) and LPG

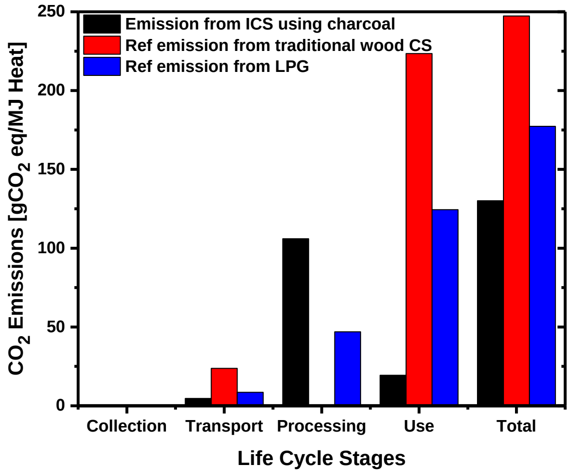

Table 4.5. Summary of life cycle greenhouse gas emissions from charcoal used in improved cookstoves compared to traditional wood (open fires) and LPG

Emission	Life cycle stages	Emission from ICS using charcoal (gCO_2eq / MJ heat)	Reference emission from traditional wood (open fires) (gCO_2eq / MJ heat)	Reference emission from LPG (gCO_2eq / MJ heat)	Difference in emissions(charcoal ICS over traditional wood – open fires)		Difference in emissions (charcoal ICS over LPG)	
					In percent (%)	Per functional unit (g CO_2eq / MJ heat)	In percent (%)	Per functional unit (gCO_2eq / MJ heat)
CO_2eq	Collection	0	0	0	-	-	-	-
	Transport	4.69	23.78	8.56	-80	-19.09	-45.2	-3.87
	Processing	105.97	0.00	46.97	-	+105.97	+126	+58.99
	Use	19.40	223.51	124.40	-91	-204.11	-84	-105.01
	Total	130.06	247.29	177.32	-47	-117.23	-27	-47.26

4.1.6 Main conclusions and recommendations

BIOGAS

Synthesis of the findings
The greenhouse gas emission from biogas per unit of heat is smaller than the emission from solid biomass and charcoal. Moreover, the use of biogas from manure has a good potential to offset the greenhouse gas emission from enteric fermentation.

Practices and policies to improve sustainability
Minimizing leakages of greenhouse gases during the processing of manure biogas can significantly decrease the greenhouse gas emissions as most of it comes from the processing stage of its life cycle. The ongoing National Biogas Programme (NBPE) and those supported by NGOs such as SNV can play a decisive role in innovating the fermentation process by upgrading the biogas and promoting its use with higher-efficiency cookstoves. Research institutes could also play a decisive role in bringing quicker changes by offering evidence-based advice regarding improving energy efficiency of biogas cookstoves.

Future monitoring
Future research and development works should widen the scope of this life cycle analysis from gate-to-gate to cradle-to-grave by including emissions from fodder production and enteric fermentation. Consequently, the comparison of emissions from chemical fertilizers with the one obtained from slurry of the biodigester would also be of interest.

FIREWOOD

Synthesis of the findings
The solid biomass pathway emits 95 per cent of the greenhouse gas (per unit of heat) during the use stage of its life cycle. Even if the emissions are much smaller than open fires, improved cookstove innovations remain indispensable to bring a significant reduction in greenhouse gas emissions.

Practices and policies to improve sustainability
The government and NGO-sponsored large-scale improved cookstove dissemination programmes should be strongly supported. In particular, the thermal efficiency improvement of stoves should be given priority in the projects of the Environment, Forests and Climate Change Commission of Ethiopia and other partners.

Future monitoring
In the current version of the analysis, biomass burning is considered to emit zero biogenic CO_2 assuming that the wood would grow again and that there is no land-use change induced by the growing and use of bioenergy. This follows the recommendation of the Intergovernmental Panel on Climate Change. More information on land-use dynamics would be useful to calculate the carbon stock in the country.

Better knowledge on the transport of firewood and the efficiency of the cookstoves in real conditions would be useful to better know the associated greenhouse gas emissions. Future research and development activities should widen the scope of this life cycle analysis to at least cradle-to-grave by including emissions data from tree planting and growing. Systematic, comprehensive and reliable inventory database of greenhouse gas emissions from all the life cycle stages of biomass should be established and updated regularly. It is commendable to expand this life cycle analysis to end-point impact assessment so that the results can be understood in light of comprehensive impact categories. For example, end-point impact assessment gives information on the impacts on climate change and human health, instead of looking into emissions only in terms of the global warming potential.

CHARCOAL

Synthesis of the findings

Innovating the charcoal processing life cycle stage and finding a regulated way of implementing improvements is crucial since the processing life cycle of the charcoal produces 80 per cent of the greenhouse gas emissions. The use stage of the charcoal's life cycle emission is lower than that of the solid biomass.

Practices and policies to improve sustainability

Better knowledge on the transport of charcoal, the efficiency of the processing and the efficiency of the cookstoves in real conditions would be useful to better know the associated greenhouse gas emissions.

Data on the production, distribution and sale of charcoal are unreliable because charcoal making is prohibited, except in a few special cases. Prohibition of charcoal making has exacerbated the degradation of woodland on top of making charcoal production a sinful act and one of the lowest-priority areas for innovation research. Complexity of the problem calls for close partnership in innovating the charcoal production process between the Ethiopian government (the forest, environment and energy sectors), rural youth and research institutes.

Application of blockchain technology could be one of the most effective ways to prove the legality and sustainability of charcoal manufacturing. In this regard, the Ministry of Innovation and Technology of Ethiopia initiated a programme that tests the use of blockchain technology in tracking and certifying agri-products in which charcoal production process can be included. Parallel with the introduction of innovative tools for tracking and authentication, programmes geared towards development, introduction and adoption of improved charcoal making kilns should be promoted and supported.

New materials with improved thermal insulation and extended durability are being invented more frequently owing to nano and other leading-edge technologies. It is important to look out for charcoal cookstove incorporating innovations in new materials and optimal combustion. The innovations can significantly cut emissions and cost.

Future monitoring

Future research and development activities should widen the scope of this life cycle analysis to at least cradle-to-grave by including emissions from seed collection, tree planting and growing. Systematic, comprehensive and reliable inventory database of greenhouse gas emissions from all the life cycle stages of charcoal should be established and updated regularly. It is recommendable to expand this life cycle analysis to end-point impact assessment so that the results can be understood in light of comprehensive impact categories.

4.1.7 References

Bhattacharya, S.C., Albina D.O. and AbdulSalam, P. (2002). Emission factors of wood and charcoal-fired cookstoves. *Biomass and Bioenergy* 23, 453-469.

Chidumayo, E. and Gumbo, J.D. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development* 17, 86-94.

Daniel, A. (2016). *Geometrical Optimization of Biomass Cook Stove for Efficient Utilization of Energy (In case of Tikikil stove)*. A thesis research submitted in partial fulfillment of the requirement for the degree of Master of Science in thermal engineering. Addis Ababa Institute of Technology, Addis Ababa University.

Ethiopia Environment, Forest and Climate Change Commission (2019). *Distribution status of improved cookstoves in Ethiopia*. Unpublished report. Addis Ababa.

Globales Emissions-Modell Integrierter Systeme (GEMIS) (2014). Version 4.9. http://www.iinas.org/gemis-download-de.html.

Hansmann, C., Stingl, R., Prieto, O.G., Lopez, C.B. and Resch H. (2008). High-frequency energy-assisted vacuum drying of fresh E. globulus. *Drying Technology* 26(5), 611-616.

Mamuye, F., Lemma, B. and Woldeamanuel, T. (2017). Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia, *Sustainable Environment Research* 28, 32-38. https://doi.org/10.1016/j.serj.2017.09.003.

SNV Netherlands Development Organisation, Strengthening Enabling Environment in Clean Cooking Sector (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia. Strengthening the Enabling Environment for Clean Cooking Project,* Final Report.

Tumwesige, V., Fulford, D. and Davidson, G.C. (2014). *Biogas appliances in Sub-Sahara Africa*.

4.2 Indicator 2. Soil quality

4.2.1 Researcher(s)

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4.2.2 Definition

(2.1) 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.

4.2.3 Measurement unit(s)

Percentage

4.2.4 Overall methodology of the implementation

Soil quality encompasses three basic components: physical, chemical and biological attributes of the soil. Various soil quality indicators are used to evaluate different land-use types. The most popular indicators used to assess soil quality are soil organic carbon, total nitrogen and soil acidity (pH). Several studies have given credence to the role of soil organic carbon in improving soil physical, chemical and biological properties. Soil organic carbon plays a major role in soil productivity because it represents the dominant reservoir and source of major plant nutrients (e.g., nitrogen, phosphorus, sulphur). It also influences pH, cation exchange capacity, anion exchange capacity, water status and soil structure. Total nitrogen is the main nutrient used for vegetation growth and is also used as a key soil quality assessment. Soil pH is one of the most important soil parameters and is essential for plant growth and productivity.

The analysis was made at a national level rather than based on the selected bioenergy pathways. Secondary sources from existing international and national studies have been used to describe the soil quality of Ethiopia.

4.2.5 Key findings

Overview of the forests in Ethiopia
Ethiopia is a vast country (1,104,300 km^2). It has a huge biomass energy potential with estimates putting the national woody biomass stock at 1,149 million tons (United Nations Environment Programme [UNEP] 2017).

Based on the revised national forest definition (Ministry of Environment Forest and Climate Change [MEFCC] 2018), the total forest cover is estimated at close to 17.35 million ha (15.7 per cent of the country area). These resources include natural forests, bamboo, dense acacia-dominated woodland (collectively called natural forest) and planted forests comprising public industrial plantations and private woodlots. Natural forests account for around 91 per cent of total forest area. Montane forests are the main constituents of the natural vegetation, of which dry Afromontane forms the largest part. Privately owned plantations and woodlots cover 5 per cent, and a small area of forest (about 1 per cent) is covered by publicly owned forest plantations.

The forest sector review in 2015 revealed that the annual volume of wood harvested for solid biomass (charcoal and firewood) is around 120.4 million m^3 of roundwood equivalent, of which 115.0 million m^3 was used as firewood and 5.4 million m^3 for conversion into charcoal (MEFCC 2018). The forest sector review document released in 2015 has been reviewed by UNEP (2016). This study pointed out that the majority (93 per cent) of solid biomass (firewood and charcoal) is sourced from natural forests, woodlands and area exclosures. The remaining 7 per cent is harvested from public and private plantations and woodlots.

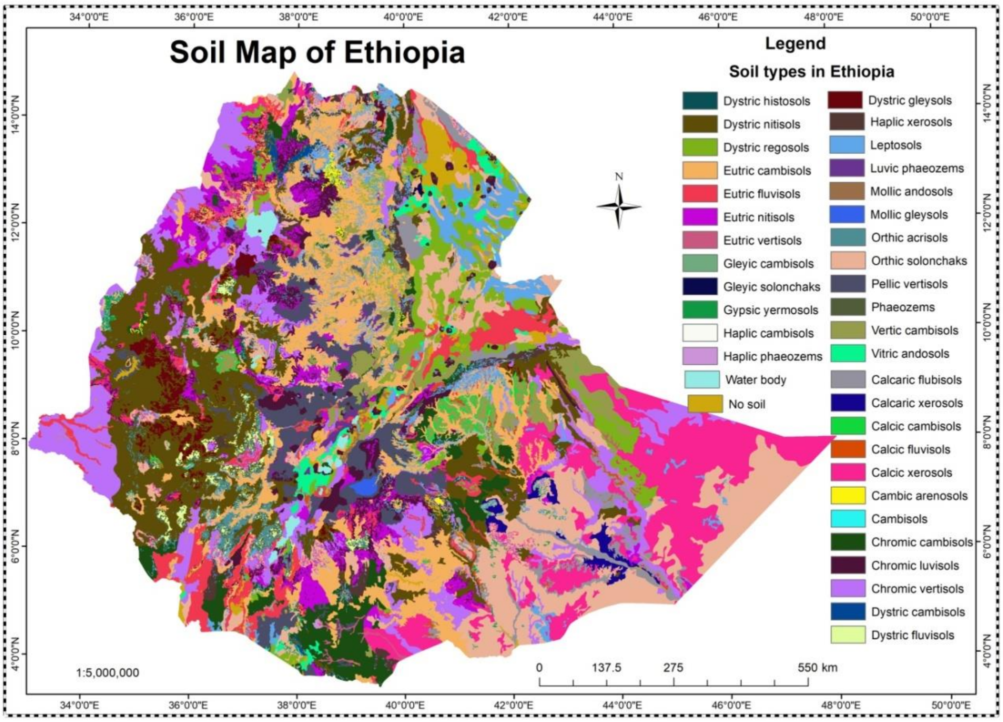
Ethiopian soils are undergoing severe mining of nutrients because of rapid population growth. Among other factors, severe agricultural expansion, soil loss, deforestation, habitat loss, degradation and fragmentation are the major threats. Due to land shortage, expansion to marginal lands and protected areas has also become a common practice. Consequently, the Ethiopian soil is currently affected by multiple issues that negatively impact the physical, chemical and biological condition of soil health and soil fertility.

Available studies
Between 2017 and 2018 the Ethiopian Environment and Forest Research Institute (EEFRI) in collaboration with Natural Resources Institute Finland (NRIF) collected 123 soil samples from 43 sites in different regional states of the country. The sampled sites encompassed different forest ecosystems, and most sampling sites were covered in Oromia regional state and SNNPR. In the Tigrai and Amhara regions, soil samples were collected from four sites only. From all sampling sites, soil samples were collected in three soil increments (0-10, 10-20 and 20-30 cm).

The study carried out by EEFRI and NRFI was mainly focused on soil bulk density and soil organic carbon determination to produce national estimates for soil carbon stocks of forests. So it does not fully assess the effect of the different forest ecosystem on all relevant factors that define the soil quality. On the other hand, across the nation useful studies on soil qualities of different forest ecosystem have been assessed by researchers and different institutes. These secondary sources of information were consulted to draw the range of soil organic carbon per cent and other soil quality parameters (Table 4.6).

Types of soil in Ethiopia
Soil types in Ethiopia are highly complex and dependent on the complicated topography. Types of soils have not yet been well described in the literature, and the classifications are therefore broad overviews based on the FAO soil classification systems. In general, 18 major soil types are found in Ethiopia, with more than 82 per cent of them represented by Leptosols, Vertisols, Nitisols, Gypsisols, Calcisols and Cambisols. From this figure around 24 per cent of the soil types are represented by Leptosols (Map 4.1).

Map 4.1. Major soil types map of Ethiopia



Source: Food and Agriculture Organization [FAO] *et al*. 2012.

According to the International Union of Soil Sciences Working Group World Reference Base for Soil Resources (WRB), Leptosols are often characterized by shallow soils over hard rock or highly calcareous material or a deeper soil that is extremely gravelly and/or stony (WRB 2015). In Ethiopia Leptosols are particularly widespread in montane areas where some of the Afromontane forest vegetations are located. Erosion is the greatest threat to Leptosol areas of Afromontane vegetation where high population pressure, overexploitation, encroachment and grazing lead to deterioration of forests and threaten large areas of vulnerable Leptosols and Nitosols (Woldu 1999).

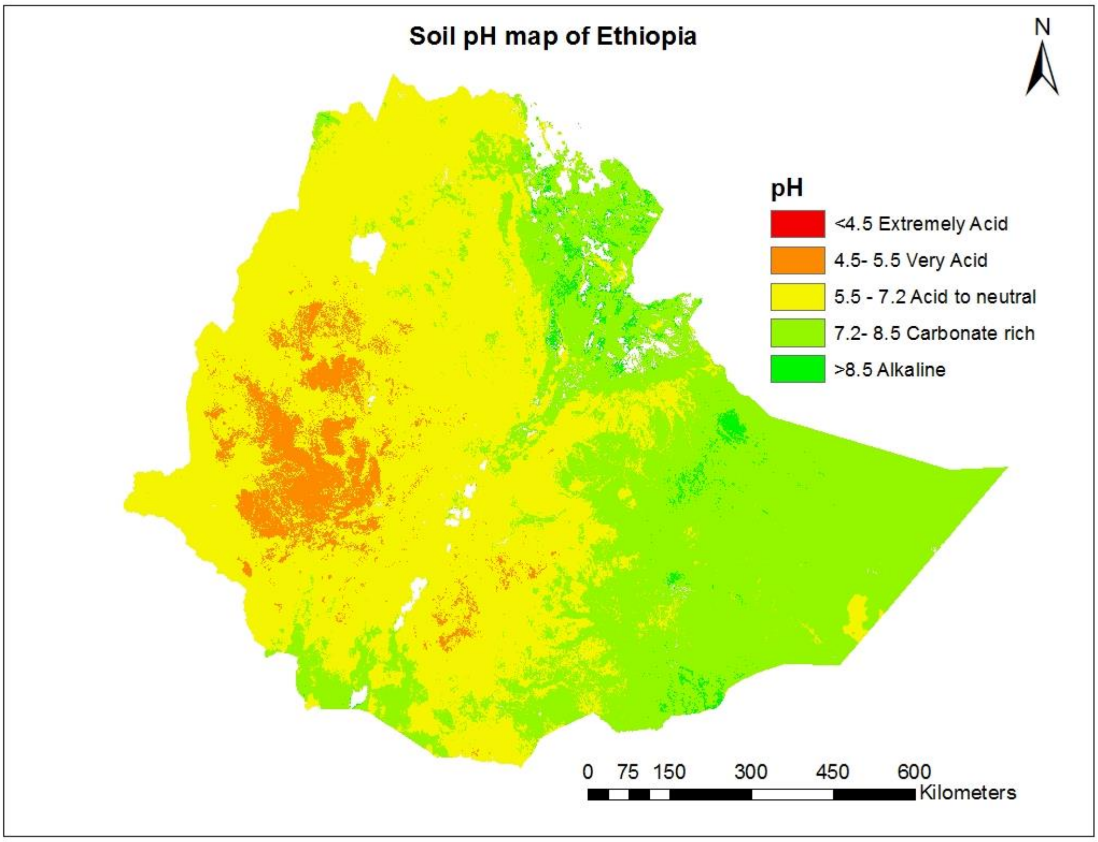
The other three important soil types groupings in terms of total area covered are: Cambisols, Fluvisols and Regosols (Map 4.1). The major dominant soil association in the Afromontane rain forest region of the country is Dystric Nitosols. Whereas, dry Afromontane forest soil of the country is well-drained and reflects the general increase in rainfall with elevation and slope, causing a decline in topsoil pH and a change from cation-rich clay soils (Mollic Nitisols/Typic Palehumults) to strongly leached Humic Umbrisols/Humic Dystrudepts in the upland forest.

Contrary to Afromontane vegetations, soil types of woodland ecosystems, which is the major source of fuel wood and charcoal, vary depending on the locations and altitudes. For example, soil types of the Combretum-Terminalia Woodland of northern Ethiopia are predominantly Haplic Luvisols, and Vertisols are the second most abundant soil types (ILRI 2005). Soils of these ecosystems are dominated by the influence of the level terrain, making rainy season waterlogging a common phenomenon. On the other hand, the major soil units of acacia woodlands that are found within the Rift Valley, the water regime together with the accumulation of basic cations led to the formation characterized by Vertisols (Mazic Vertisols/Aridic Haplusterts) (Fritzsche *et al.* 2007).

Ethiopian forest soil quality

More than 50 per cent of Ethiopian soils are generally acidic in nature (Map 4.2). Studies carried out in different Afromontane vegetation areas showed that all surveyed forest soil types in such ecosystem tend to be acidic, and average values fall within the range of 5 to 7 (see references cited in Table 4.6). Soil organic carbon, total nitrogen and pH can be used effectively in sustainable forest management if threshold values are identified.

Map 4.2. Soil pH map of Ethiopia

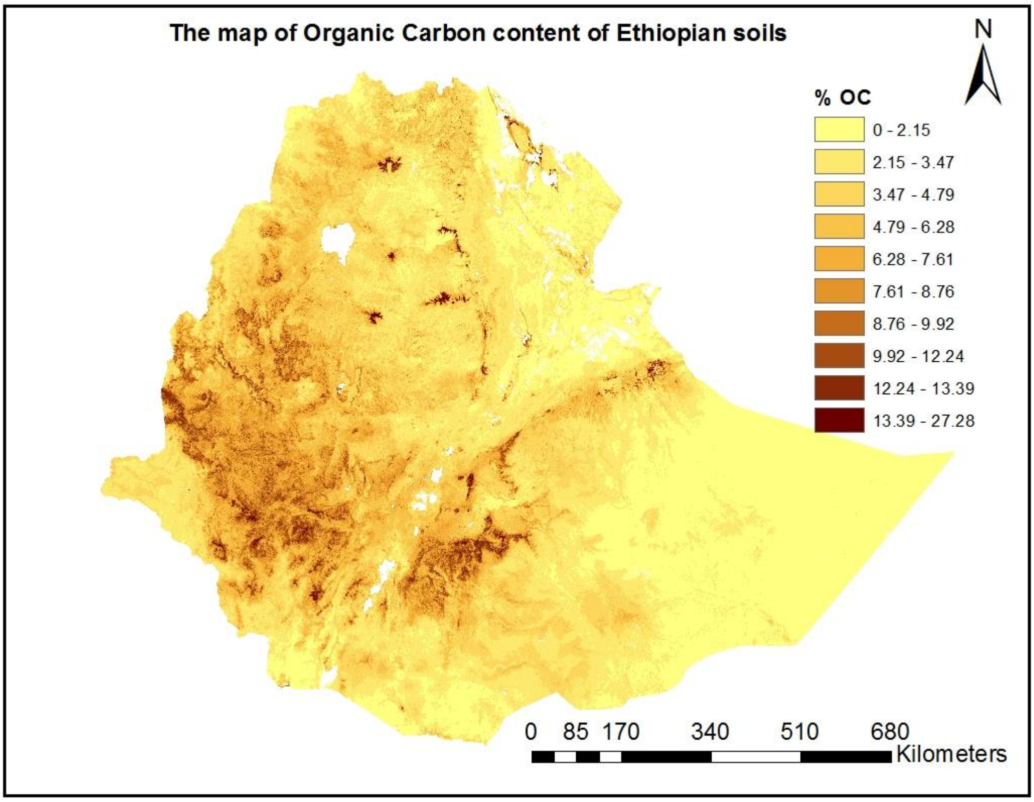


Source: FAO *et al*. 2012.

Most soil samples from the study sites carried out by different researchers and institutes are brownish and exhibited hue, the dominant spectral color or quality, values of about 10YR and 7.5YR and becoming reddish with decreasing elevation. According to the soil sampling carried out by EEFRI and NRFI, from 0-10 cm soil depth, average soil organic carbon across the sampling sites ranged from 1 per cent to 7.7 per cent. From the same soil depth, the subset of 123 soil samples from the respective regions indicated that the average soil organic carbon was 2.7 per cent (Amhara), 3.7 per cent (Oromia), 3.9 per cent (Tigrai) and 4.4 per cent (SNNPR).

Unlike plant nutrients or soil pH levels, there are few accepted guidelines for adequate organic matter content in particular soils. However, the soil organic carbon threshold for sustaining soil quality in tropical agroecosystems is widely suggested to be about 2 per cent, below which deterioration may occur (Patrick *et al.* 2013). Based on this, overall Ethiopian forest soil can be considered as adequate to soil plant nutrition. The map of organic carbon content of Ethiopian soils shows that forested regions in the central, southern and southwestern parts of the country exhibit distinctively larger values of organic carbon than those of other regions, with substantial areas showing less than 25 g kg^{-1} of organic carbon (Map 4.3).

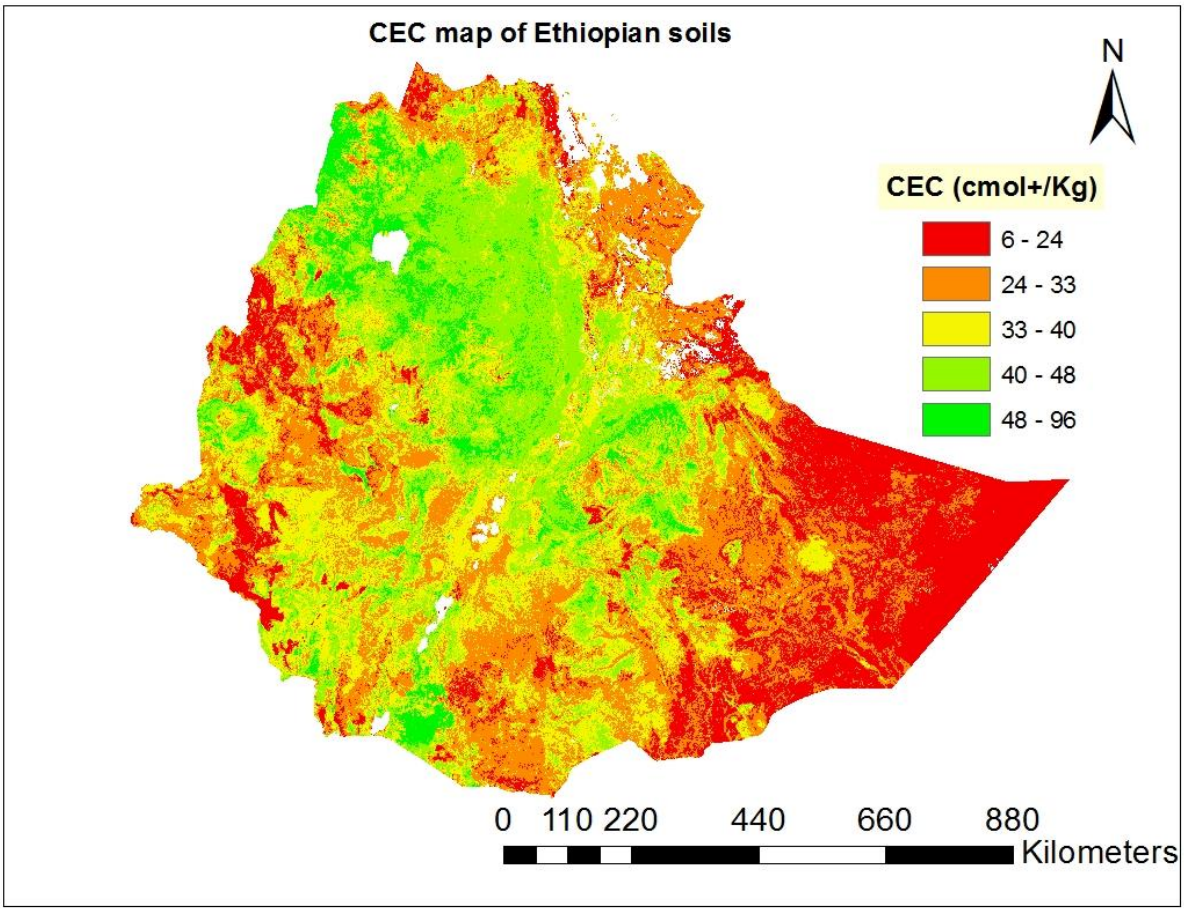
Map 4.3. Map of organic carbon content in topsoil (0-5 cm) of Ethiopia



Source: FAO *et al*. 2012.

The majority of Ethiopian woodland vegetation soils tend to be more yellowish, reddish or brown depending on the hydration of ferric oxide and extensive weathering of the parental mineral content. For example, the color of surface horizons of northern woodlands varied from brown (7.5YR 4/4) to dark yellow-brown (10YR 4/4) and dark brown (7.5YR 3/4) to dark yellowish-brown (10YR 3/4) when they were dry and moist (Eshete *et al*. 2011). The average cation exchange capacity (CEC) of Ethiopian soils ranged from 6 to 96 cmol kg^{-1} (Map 4.4). As compared to woodland vegetation areas, the CEC of Afromontane forest soils is larger (Map 4.4). In general, the CEC of soil sampled from different forest ecosystem explored by researchers ranged from 25 to 75 cmol kg^{-1}. In all profiles sampled the main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}) that contribute more than 30 per cent (by charge). The exchangeable cations content can be arranged in series of decreasing values: Ca>>>Mg>>K>Na.

Map 4.4. Cation exchange capacity map of Ethiopia from 0-5 cm soil depth



Source: FAO *et al.* 2012.

Table 4.6. Characteristics of selected soil properties of major woody biomass sources of vegetation types

Soil characteristics	Major woody biomass sources of vegetation types [1]				
	Dry evergreen Afromontane forest	Moist evergreen Afromontane Rainforest	Acacia-Commiphora woodland and bushland	Combretum-Terminalia woodland and wooded grassland	Desert and Semi-desert scrublands
Parent materials	Plinthaquic Paleudalf Antalo Limestone Dithiotrachytes and basalts	Basaltic, trachitic Granite, gneisses, schist, sandstone, and basalt	Cretaceous limestone, sedimentary volcanic rocks, Ignimbrites and pumices	Granite, Gneisses and Migmatites	Alluvial, Basaltic rocks, lava flows and limestone
Type	Nitisols, Umbrisols, Regosols and Cambisols	Plinthosols, Cambisols, Vertisols, Planosols, Nitosols, Acrisols,	Andosols, vertisols, Alluvial	Luvisols, Regosols, Lithosols, Humic, Mollic, Andosols, vertisols	Cambisols, Yermosols Xerosols,Eutric Fluvisol and Solonetz
Color	Dark reddish brown to black	Red, red brown to black	Dark yellowish-brown Reddish, Brown	yellow, brown, grey or red	reddish brown, dark gray
pH	5 – 8	5.3 - 8.1	6.6 - 8.7	4.98 - 8.28	7.4 - 9.1
Organic carbon (%)	1.8 - 5.2	2.4 - 6.0	1.5 - 3.2	0.8 - 3.7	0.5 - 1.5%
Total nitrogen (%)	0.08 - 0.15	0.06 - 0.22	0.07 - 0.12	0.02 - 0.29	0.01 - 0.07
References	Mohr 1971; Solomon *et al*. 2002; Aerts *et al.* 2006; Fritzsche Zech, Guggenberger 2007; Yohannes *et al.* 2011; Adugna and Abegaz 2015; FAO 2015; Eyasu 2016	Mohr 1971, Asres 1996; Solomon *et al.* 2002; Gole 2003; Yimer, Ledin and Abdelkadir 2006; Yimer Ledin and Abdelkadir 2007; FAO 2015; Eyasu 2016	Mohr 1971; Solomon *et al.* 2002; Fritzsche, Zech, Guggenberger 2007; FAO 2015, Eyasu 2016	Mohr 1971; Kamara and Haque 1987; Coppock 1994; Fritzsche Zech, Guggenberger 2007; Eshete, Sterck, and Bongers 2011; Dalle *et al.* 2014; FAO 2015; Eyasu 2016	Mohr 1971; Friis Demissew and van Breugel 2010; FAO; 2015; Eyasu 2016; Mesene and Kabtamu 2017; Megersa and Worku 2018

[1] Types of vegetation cited according to Friis, Demissew and van Breugel (2010)

Impact of the use of biomass on soil quality

Soils are the literal fundament of cultivating solid biomass feedstocks. Thus, ensuring and sustaining soil quality is fundamental for the future productive use of land. Extraction of solid biomass for use as an energy source or for any other purposes leads to soil quality deterioration. Usually, negative impacts of biomass harvesting on soil nutrient pools (e.g., nitrogen, phosphorus and base cations) and soil acid-base status are more frequent in the forest floor than in the mineral soil (Raulund-Rasmussen *et al.* 2008). Over time, reduced soil carbon contents are generally expected following solid biomass extraction. Field-based studies revealed a slight tendency towards reduced soil nitrogen following tree harvesting (Carter *et al.* 2002).

Furthermore, harvesting of boles, branches and leaves particularly from nutrient poor sites may lead to soil acidification. Understanding the consequences of solid biomass extraction activities on soil organic carbon and other parameters is critical to enhancing and managing soil quality. Thus, management of soil quality involves management of the soil organic carbon pool. Since agroecologies, and soil types found in the country differ from place to place, generalizations are difficult to make for different vegetation types in the management of soil organic carbon. Therefore, it is pertinent to identify site-specific indicators of soil quality that can be used as a reference for the impact of biomass utilization on specific soil quality parameters.

The potential of manure or digestate

Manure or digestate, whether alone or in mixture with compost, is considered to have potential as an effective soil amendment for restoration of degraded lands and forests to forestry end use. However, to our knowledge there is no single experience all over the country on the effects of digestate application on forest ecosystem and degraded land to fully exploit the digestate potential as such. Moreover, considering the existing number and distribution of biogas plants across the nation, it may not be feasible to transport the slurry to a central location and package it for sale and use as a source of fertilizer. But it is easily applicable and reasonable to handle the slurry at the plant premises where some of the biogas villages are found. As a result, the loss of nutrients from slurry collection point is substantial.

Regarding this, there is a good experience initiated by SNV Ethiopia, which has engaged LCB / Institute for Sustainable Development to help in the documentation of knowledge on the use of bioslurry from farmers' practices and from on-farm research trials by using experts and MSc students from Ethiopian universities (Eshete 2011). Trials on farmers' fields conducted by the initiatives have shown beneficial effects of bioslurry organic fertilizers in the form of liquid in increasing the yields of wheat crops, fruit trees and vegetables in their homesteads. In urban areas, Butajira municipality, for example, has started to collect bioslurry from these households for the greening project of Butajira town. The bioslurry is collected from each urban household using a plastic tanker purchased and distributed by the municipality.

There are also entrepreneurs in some localities who make a compost using bioslurry together with agricultural residue, biodegradable kitchen wastes, etc. These entrepreneurs have already come forward to produce and market organic fertilizers. There is a need to compile the existing local practices and other countries' experiences to scale up bioslurry utilization technologies in forestry development; it is applicable especially for tree seedling production in a nursery. On the other hand, in order to market and promote bioslurry organic fertilizers, there is a need to formulate a national programme, so that both biogas for household cooking and bioslurry as organic fertilizer can be used effectively.

4.2.6 Conclusion and recommendations

Synthesis of the findings

Ethiopia's energy requirement in households is met mainly with biomass fuels sourced from the natural forests and woodlands, and some is sourced from unidentified sources. To meet the ever-increasing population growth, charcoal production, which is largely informal, is expected to continue to increase in the future. Given rising demand for solid biomass, a continuation of unsustainable production and use can be expected to exacerbate climate change, which, in turn, could affect the health and productivity of forests and woodlands and thereby reduce future wood-energy supplies in many places of the country.

The evidence indicates that the harvesting and production technology systems in the nation are unsustainable. Thus, misuse of the natural resources and obsolete technologies has a direct link to the worsening of the forest resource depletion, soil and environmental degradation. Due to rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing, land degradation and soil nutrient depletion are more serious in the marginal highlands of the northern parts of the country than elsewhere (Tamene and Vlek 2008).

Practice and policies for sustainable utilization of solid biomass

Land is a fundamental issue closely related to biomass in general, and to bioenergy in particular. Therefore, the sustainability of biomass or bioenergy depends on the productivity of the land use. Different options are available to improve the efficiency and sustainability of solid biomass production related to soil quality. The soil quality can be improved using the existing local and international experience such as sustainable forest management; sustainable community-managed woodlots plantations and agroforestry. It is necessary to protect high-biodiverse areas, including existing protected areas. Specific activities to cultivate and harvest solid biomass and to manage their extraction have to be addressed in terms of their compatibility with different forest types.

To assure that the cultivation systems and practices maintain or improve soil quality, the soil organic carbon content of land being used for solid biomass resources cultivation or for extracting surplus biomass growth must be at least maintained. In this regard, more work is necessary to complete the nationally available GIS data concerning high potential solid biomass areas, and updates of the existing GIS data with a sufficiently high resolution are required for many solid biomass sources found in different agroecologies. To cement such initiatives, there is a need to develop comprehensive national policy frameworks for the sustainable management of solid biomass production that directly affects the soil organic carbon and to integrate this effort across any biomass development sectors.

Future monitoring

Because of the diverse agroecology, soil types and methodologies employed, the literature on percentage of soil organic carbon, total nitrogen and pH values in Ethiopian soil varies. Soil quality indicators such as organic matter content, total nitrogen and pH can only be used effectively in sustainable forest management if threshold values are identified Therefore, it is important to create soil organic carbon, total nitrogen and pH databases and to set threshold values for representative forest types using standard and uniform soil sampling methodologies that are simple and cost effective to measure, and are applicable to the majority of forest ecosystems. Regarding this, there is a need to continue to research these soil quality indicators, and EEFRI and other higher learning institutes are taking the lead to accomplish the task. These institutes should work in collaboration to use long-term soil monitoring data to test whether soil indicators can identify trends that can be useful for sustainable forest management

4.2.7 References

Adugna, A. and Abegaz, A. (2015). Effects of soil depth on the dynamics of selected soil properties among the highland's resources of Northeast Wolega, Ethiopia: are these signs of degradation? *Solid Earth Discussion* 7, 2011-2035.

Aerts, R., Van Overtveld, K., Haile, M., Hermy, M., Deckers, J. and Muys, B. (2006). Species composition and diversity of small Afromontane forest fragments in northern Ethiopia. *Plant Ecology* 187, 127-142. https://doi.org/10.1007/s11258-006-9137-0.

Asres, T. (1996). *Agroecological zones of southwest Ethiopia*. Matreialien Zur Ostafrica-Forschung, Heft 13.

Carter, M.C., Dean, T.J., Zhou, M., Messina, M.G., and Wang, Z. (2002). Short-term changes in soil C, N, and biota following harvesting and regeneration of loblolly pine (*Pinus taeda* L.). *Forest Ecology & Management* 164(1-3), 67–88. doi:10.1016/S0378-1127(01)00590-4.

Coppock, D.L. (1994). *The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change, 1980-91*. International Livestock Centre for Africa Systems Study 5, Addis Ababa, 393.

Dalle, G., Brigitte, L. Maass, B.L. and Isselstein, J. (2014). Relationships between vegetation composition and environmental variables in the Borana rangelands, southern Oromia, Ethiopia *Sinet: Ethiopian Journal of Science* 37(1), 1-12.

Eshete, A., Sterck, F.J. and Bongers, F. (2011). Diversity and production of Ethiopian dry woodlands explained by climate – and soil – stress gradients. *Forest Ecology & Management* 261, 1499-1509. https://doi.org/10.1016/j.foreco.2011.01.021.

Eshete, G. (2011). Bio-slurry: Is it a fertilizer in the making? SNV Netherlands Development Organisation, Case studies.

Eyasu, E. (2016). *Soils of the Ethiopian Highlands: Geomorphology and Properties*. CASCAPE Project, ALTERA, Wageningen University and Research Centre. Wageningen, the Netherlands. 385.

Food and Agriculture Organization of the United Nations (1984). *Assistance to Land Use-Planning, Ethiopia: Geomorphology and Soils. Field Document AG DP/ETH/78/003.* United Nations Development Programme and FAO. Rome.

Food and Agriculture Organization of the United Nations, International Institute for Applied Systems Analysis, International Soil Reference and Information Centre, Institute of Soil Science – Chinese Academy of Sciences and Joint Research Centre of the European Commission (2012). Harmonized World Soil Database (version 1.2). FAO, Rome, and IIASA, Laxenburg, Austria. http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/.

Friis, I., Demissew, S. and van Breugel, P. (2010). *Atlas of the Potential Vegetation of Ethiopia*. The Royal Danish Academy of Science and Letters, Copenhagen, Denmark.

Fritzsche, F., Zech, W. and Guggenberger, G. (2007). Soils of the main Ethiopian Rift Valley escarpment: A transect study. *Catena* 70, 209–219. https://doi.org/10.1016/j.catena.2006.09.005.

Gole, T.W. (2003). *Conservation and Use of Coffee Genetic Resources in Ethiopia: Challenges and Opportunities in the Context Current Global Situations.* Bonn. http://www.coffee.uni-bonn.de/download/Tadesse-W-Gole_2003_Conservationand-Use-of-Coffee-genetic-Resources-in-Ethiopia.pdf.

International Livestock Research Institute (2005). *Metema Pilot Learning Site Diagnosis and Program Design.* International Livestock Research Institute. Unpublished. Addis Ababa. 1-100 pp.

IUSS Working Group World Reference Base (2015). *World Reference Base for Soil Resources, update 2015. International soil classification system for naming soils and creating legends for soil maps.* World Soil Resources Reports N 106. Food and Agriculture Organization of the United Nations. Rome.

Kamara, C.S. and Haque, L. (1987). *Characteristics of Vertisols at ILCA research and outreach sites in Ethiopia.* Plant Science Division Working Paper 85. International Livestock Centre for Africa. Addis Ababa. 69 pp. [ILCA library accession no. S-93, N.B51].

Megersa, B. and Worku, A. (2018). Impact of tree species in different sub-habitats on soil physico-chemical properties of Allaidege rangeland, Southern Afar, Ethiopia. *Asian Journal of Science and Technology*, 9(01): 338-346.

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Program, Ethiopia. Volume I: Situation Analysis*. Addis Ababa.

Mohr, P.A. (1971). *The Geology of Ethiopia*. University College of Addis Ababa, Central Printing Press, Addis Ababa.

Patrick, M., J.S. Tenywa, P. Ebanyat, M.M. Tenywa, D.N. Mubiru, T.A. Basamba *et al*. (2013). Soil organic carbon thresholds and nitrogen management in tropical agroecosystems: Concepts and prospects. *Journal of Sustainable Development* 612, 31-43.

Raulund-Rasmussen, K., Stupak, I., Clarke, N., Callesen, I., Helmisaari, H.-S., Karltun, E. *et al.* (2008). Effects of very intensive forest biomass harvesting on short and long-term site productivity. In *Sustainable Use of Forest Biomass for Energy. A Synthesis with Focus on the Baltic and Nordic Region.* D. Röser, A. Asikainen, K. Raulund-Rasmussen, and I. Stupak (eds.) Springer. Dordrecht, The Netherlands. 29-78.

Solomon, D., Fritzsche, F., Lehmann, J., Tekalign, M. and Zech, W. (2002). Soil organic matter dynamics in the sub-humid agroecosystems of the Ethiopian Highlands: Evidence from natural carbon abundance and particle-size fractionation. *Soil Science. Society of America Journal* 66, 969-978. doi:10.2136/sssaj2002.9690.

Tamene L. and Vlek P.L.G. (2008). Soil Erosion Studies in Northern Ethiopia. In: Braimoh A.K., Vlek P.L.G. (eds.). *Land Use and Soil Resources*. Springer, Dordrecht, The Netherlands.

United Nations Environment Programme (2016). *The Contribution of Forests to National Income in Ethiopia and Linkages with REDD+*. Nairobi.

United Nations Environment Programme (2017). *Atlas of Africa Energy Resources*. Nairobi.

Yimer, F., Ledin, S. and Abdelkadir, A. (2006). Soil organic carbon and total nitrogen stocks as affected by topographic aspect and vegetation in the Bale Mountains, Ethiopia. *Geoderma* 135, 335-344. https://doi.org/10.1016/j.geoderma.2006.01.005.

Yimer, F., Ledin, S. and Abdelkadir, A. (2007). Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. *Forest Ecology & Management* 242, 337–342. https://doi.org/10.1016/j.foreco.2007.01.087.

Yohannes, Y., Shibistova, O., Abate, A. Fetene, M. and Guggenberger, G. (2011). Soil CO_2 efflux in an Afromontane forest of Ethiopia as driven by seasonality and tree species. *Forest Ecology & Management* 261, 1090-1098.

4.3 Indicator 3. Harvest levels of wood resources

4.3.1 Researchers

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4.3.2 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.

4.3.3 Measurement unit(s)

M^3/ha/year, tons/ha/year, m^3/year or tons/year, percentage

4.3.4 Overall methodology of the implementation

The indicator applies to bioenergy production from wood resources and forestry residues, according to nationally defined forest type. It applies therefore more particularly to the pathway on solid biomass. Some comments are also provided on the pathway on biogas. The analysis mainly focused on the national situation.

Secondary data sources (literatures, reports, survey results, national figures, etc.) on forest cover, forest productivity, annual harvest of wood resources and firewood specifically were used. Data on net annual growth and sustained yield, disaggregated by region, were not available when the testing was carried out.

4.3.5 Key findings

BIOGAS

Biogas plants have various social, economic, environmental and climatic impacts. Biogas offers an attractive option to replace unsustainable utilization of wood and charcoal as a household fuel source. According to a survey in Ministry of Water, Irrigation and Energy [MoWIE] (2018), both biogas users and experts from different offices believe that biogas has significantly reduced the use of firewood contributing to improvement in the forest coverage. Even though the increase in forest coverage is not totally attributed to the introduction of biogas technology, it has meaningfully contributed because a majority of biogas users have fully or partially shifted from solid biomass to gaseous energy sources due to the biogas programme. The introduction of the biogas technology has also strengthened area closure because users have changed their free grazing to a cut-and-carry animal feeding system (MoWIE 2018). Therefore, the biogas being produced and utilized helped to save a huge amount of wood that could be obtained from harvesting and, thus, biogas has contributed to the conservation of forests.

Moreover, the contribution of biogas technology in reducing the time and cost of collecting traditional energy sources is greatly appreciated by the majority of biogas users (around 85 per cent of respondents) both in semi-urban (76 per cent) and rural (90 per cent) areas. Improvements in cooking, including convenience as well as speed, were given as the most advantageous reasons for using biogas compared to conventional methods (MoWIE 2018).

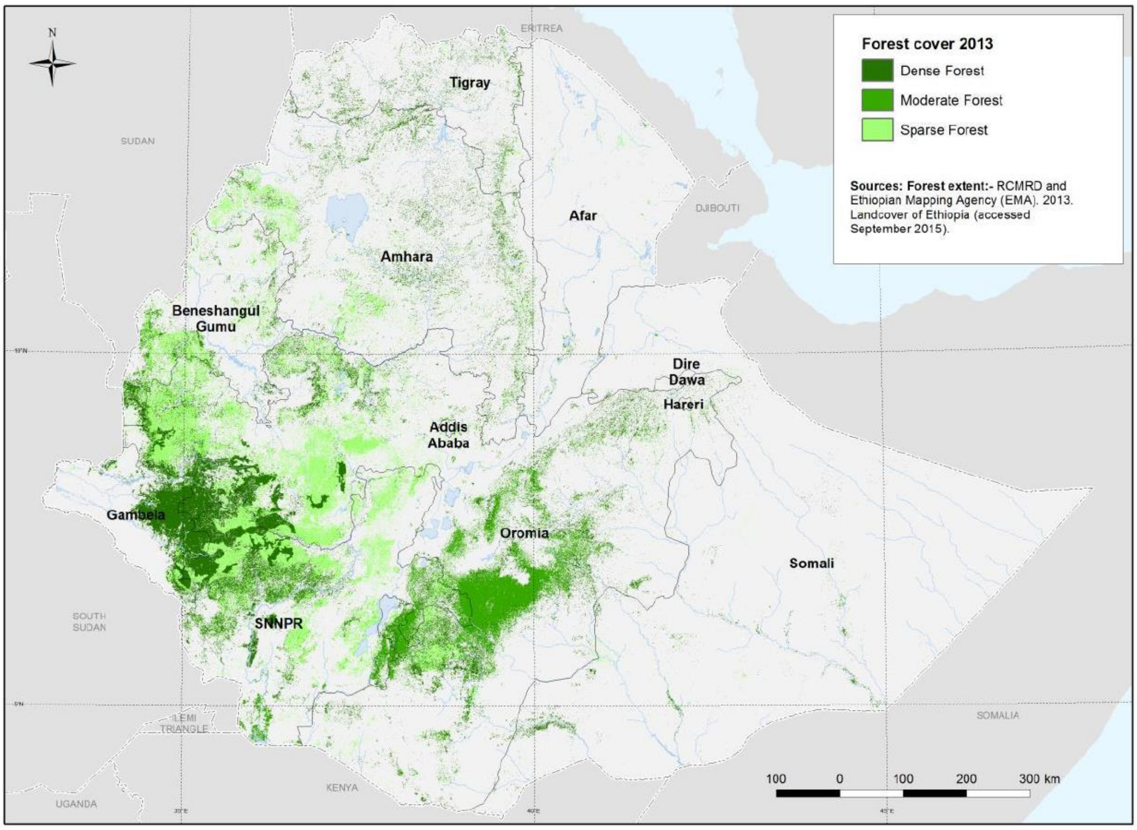
SOLID BIOMASS

Definition of forest and forest coverage
In Ethiopia forest is defined as land occupied with trees (natural and planted, including bamboo) attaining a height of more than 2 metres at maturity, canopy cover of more than 20 per cent and covering an area of more than 0.5 ha, with a minimum width of 20 metres or not more than two-thirds of its length (Ministry of Environment, Forest and Climate Change [MEFCC] 2017; MEFCC 2018a). Accordingly, the forest coverage of Ethiopia is estimated to be about 17.35 million ha or 15.5 per cent of the land mass of the country (Map 4.5 and Table 4.7) (MEFCC 2016; MEFCC 2017; MEFCC 2018a).

Ethiopia adopted this new forest definition in 2015 (MEFCC 2015). It differs from the Food and Agriculture Organization [FAO] forest definition and therefore from the definition used in the data reported to the Global Forest Resources Assessment of the FAO. The FAO forest definition includes thresholds of 10 per cent canopy cover, a 0.5 ha area and a 5 m height (FAO 2018).

The reason for changing the national forest definition is to better capture the natural primary state of Ethiopia's forest vegetation. Lowering the tree height from 5 metres to 2 metres captures natural forest vegetation types such as dry land forests, where trees reach a height of around 2-3 metres. Increasing the canopy cover threshold from 10 per cent to 20 per cent avoids acceptance of highly degraded forest lands into the forest definition and in this way provides incentives for protecting quality forest. The proposed change in forest definition results in the inclusion of what previously was classified as Ethiopia's dense woodlands that have a wider distribution through the country. Commercial agriculture is expanding mainly on dense woodlands.

Map 4.5. Distribution of the forest resources of Ethiopia



Source: EMA 2013 cited in MEFCC 2018a)

Table 4.7. Forest cover of Ethiopia

Types of forests	Ethiopian new forest definition (2015)	
	Area coverage (ha)	% of total land
Natural forest	5 266 419	4.7
Woodlands	10 739 286	9.5
Plantation forest	827 612	0.7
Bamboo forest	519 124	0.5
Total	17 352 441	15.5

Source: MEFCC 2018a.

Ethiopia has one of the largest bamboo resources in Africa. According to recent remote sensing-based inventory conducted by INBAR – Tsinghua University, Ethiopia would have a higher potential, with a total of 14,745 km^2 or 1.47 million ha of bamboo in Ethiopia (INBAR 2018 cited in Environment, Forest and Climate Change Commission [EFCCC] (2019).

Loss of forest area

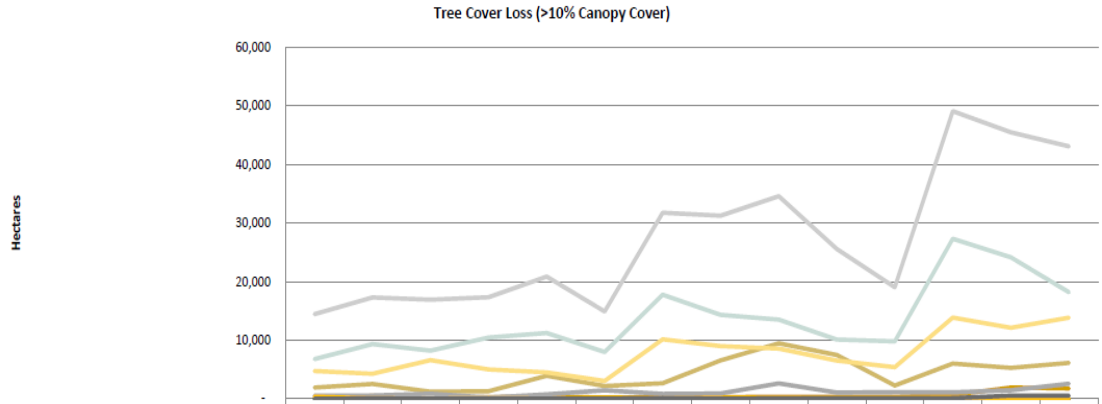
Forest loss (>10 per cent canopy cover) for the period 2001-2014 was 381,285 ha (MEFCC 2018a) (Table 4.8). Deforestation and land degradation are widespread in Ethiopia due to the high levels of human pressure and unsustainable land use. Given Ethiopia's largely rugged topography, an estimated 27 million ha of land in the highlands are degraded, of which 14 million ha are severely eroded (Berry 2003 cited in MEFCC 2018a). At the national level, the rate of deforestation and forest degradation in Ethiopia ranges from 140,000 to 200,000 ha/year and has resulted in severe land degradation and loss of biodiversity (MEFCC 2018a). There has been a continued loss of forest between 2000 and 2010. Figure 4.4 and Table 4.8 show that although there are regional differences, tree cover loss has generally been increasing in recent years.

Table 4.8. Tree cover loss and gain

Regional state	Forest loss (ha) (>10% canopy cover)	Forest gain (ha) (>50% canopy cover)
Period	**2001-2014**	**2001-2012**
Addis Ababa	335	579
Afar	72	12
Amhara	7 385	4 264
Benshangul-Gumaz	58 755	922
Dire Dawa	3	0
Gambella Peoples	15 914	1 161
Harari People	16	0
Oromia	188 960	42 351
Somali	869	251
SNNPR	107 406	12 609
Tigray	1 569	389
Total	**381 285**	**62 538**

Source: MEFCC 2018a.

Figure 4.4. Tree cover loss by region for the period 2001-2014 (>10% canopy cover)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Addis Ababa	32	3	3	3	61	8	13	8	9	16	18	75	29	58
Afar	3	3	1	4	2	3	2	3	1	1	3	8	19	18
Amhara	136	483	50	296	356	209	290	294	332	334	316	622	1,913	1,754
Benshangul-Gumaz	1,893	2,521	1,205	1,271	3,921	2,164	2,636	6,547	9,458	7,487	2,248	6,006	5,266	6,130
Dire Dawa	-	-	1	-	-	-	0	0	-	0	0	0	-	-
Gambela Peoples	503	548	853	191	737	1,433	833	889	2,619	1,052	1,145	1,098	1,458	2,554
Harari People	1	1	0	2	1	1	2	1	0	1	1	6	1	-
Oromia	6,763	9,335	8,203	10,438	11,225	7,957	17,728	14,323	13,509	10,093	9,806	27,295	24,115	18,169
Somali	354	65	6	81	24	41	30	140	45	29	18	34	2	1
Southern Nations, Nationalities and Peoples	4,719	4,261	6,566	5,007	4,477	3,032	10,140	8,994	8,536	6,505	5,396	13,830	12,110	13,831
Tigray	26	49	9	23	22	28	73	24	56	38	68	87	534	532
Total	14,430	17,272	16,897	17,316	20,825	14,875	31,746	31,225	34,566	25,557	19,020	49,061	45,448	43,046

Source: MEFCC 2018a.

The drivers of deforestation and forest and land degradation vary greatly at the regional and local levels. The main direct drivers of deforestation are small-scale agricultural expansion and fuelwood consumption, and to a lesser extent, illegal logging and forest fires (FDRE 2011 cited in MEFCC 2018a). Another important driver has been identified as large-scale agricultural investments, which until recently were promoted by the government as a vehicle for rural development and economic growth. Overgrazing, settlement, and uncontrolled tree harvesting and utilization also contribute. On public land (which is typically where forests are found), there may be no sense of ownership of the resource, leading to a tragedy of the commons problem where optimization of individual harvest levels leads to degradation of the common resource.

Growth and standing stock

Growth and standing stock in the current forest vegetation of Ethiopia is presented in Table 4.9. Actual incremental yield for the various forest vegetation is very low. For natural forest this is mainly due to over-logging in the past and lack of proper management for the remaining forest. For plantation forest, the main reason is the lack of proper silviculture and stand management.

Table 4.9. Growth and standing stock of forests of Ethiopia

Parameters	Forest vegetation		
	Natural forest	Plantation (industrial)	Plantation (woodlots)
Standing stock (m^3/ha)	48.73[(1)]	179	75
Total standing volume (m^3)	790 355 000	33 836 907	61 129 275
Mean annual increment (m^3/ ha / yr)	2.01[(1)]	12.5	15
Annual sustainable yield (m^3/year)	32 594 000		

[(1)] Note: These estimates are adjusted by means of weighted average from the data by WBISPP (2004) for high forest and woodlands. The natural forest calculations exclude bamboo forest. The larger share of the natural forest defined today is woodlands, and adjustment of the standing stock and mean annual increment is needed to arrive at a realistic sustainable yield and total standing stock.
Source: WBISPP 2004 and FSR 2015 cited in MEFCC 2018a.

The current mean annual increment of 12.5 m^3/yr/ha estimated for the industrial plantation is low compared to the potential growth of around 46 m^3/ha/yr for eucalyptus stands and 33 m^3/ha/yr for conifer stands when planted and managed on good sites (MEFCC 2018a). The current industrial plantations are not planted on good sites and not well managed. Currently, only 190,000 ha of poorly managed industrial plantations exist in the country (Forest Sector Review 2015 cited in MEFCC 2018b). According to FAO (2019), the production of roundwood in 2017 was 110.6 million m^3 (Table 4.10). This is slightly less than the 120 million m^3 supply estimated by MEFCC (Table 4.9). The reasons for the difference deserve more analysis in the future.

Table 4.10. Wood removals for the year 2017

Assortment	Production (m^3)
Round wood	113 557 000
Fuel wood (including wood used for charcoal production) [(1)]	110 622 000
Industrial wood	2 935 000

[(1)] Charcoal production is 4.4 million tons of charcoal.
Source: FAO 2019

Fuel wood supply

The total wood product demand in 2015, measured by the volume of wood consumed in the country (production import-export) is around 130.3 million m^3 of roundwood equivalent. Approximately 92.3 per cent of this is in the form of wood fuel and the rest is in the form of industrial wood (MEFCC 2018a). The annual volume of wood harvested for wood fuel is around 120.4 million m^3 of roundwood equivalent in 2015 (115.0 million m^3 as firewood and 5.4 million m^3 for conversion into charcoal) (MEFCC 2018a). Harvest per hectare is not available.

Currently, more than 90 per cent of the domestic supplies of fuel wood come from diverse sources such as natural high forests and woodlands, industrial plantations and private forests (trees outside forests including woodlots) (Table 4.11).

Table 4.11. Estimate of wood fuel supply in Ethiopia

Forest type	Estimated annual supply of fuel wood in roundwood equivalent (million m³)	Proportion (%)
Woodlots	6.6	5.48
Natural forests and woodlands (sustainable supply)	32.1	26.66
Peri-urban energy plantations	0.08	0.07
Public plantations	0.07	0.06
Area exclosures	1.64	1.36
Wood fuel from waste	0.17	0.14
Import	0.000279	0.00
Unknown source (1)	79.74	66.23
Total	120.40	100

(1) This is most likely the volume extracted from natural forests through unsustainable harvest.
Source: MEFCC 2017; MEFCC 2018a.

Unsustainable extraction of wood from forests and woodlands for the purpose of fuel wood and charcoal has contributed greatly to the loss of forest resources and to widespread degradation and deforestation. This in turn has contributed to a sustainable supply gap for the volume of fuel wood needed today (MEFCC 2018a). The loss of acacia woodland in the Central Rift Valley area is usually associated with charcoal production and firewood extraction. Acacia species are the favoured sources for charcoal production given their smooth combustion and better energy yield.

Fuel wood demand

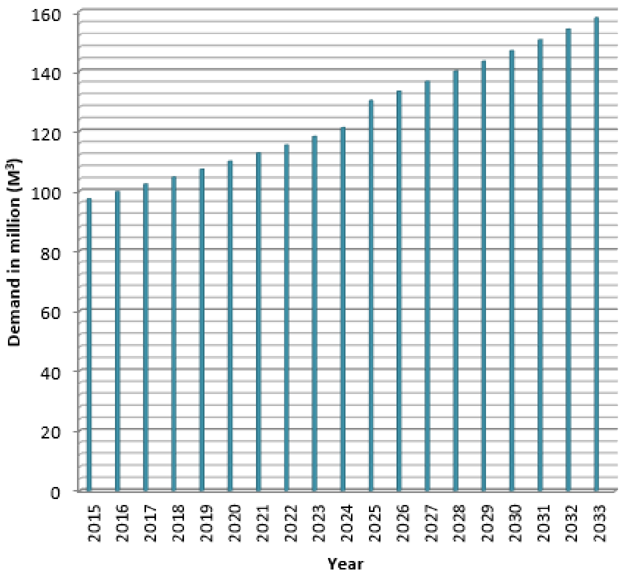
The largest source of wood-based production and consumption in Ethiopia is wood fuel (firewood and charcoal). According to recent studies, nearly 95 per cent of the nation's energy consumption comes from "biomass fuels" of which "wood fuel" is the most important, providing an estimated 68 per cent of the total (MEFCC 2018a). The vast majority of households depend on wood or charcoal for domestic energy consumption, using wood for cooking, heating and lighting. A massive increase in charcoal consumption was observed in the past 15 years due to the significant increase in rural incomes, proliferation of rural markets, improved road system and reduced transport costs and the limited land for growing trees surrounding urban areas. More details are provided in the description of the pathway (section 2 of the report).

Demand for energy for cooking and heating in Ethiopia far outstrips sustainable supply. Further, the efficiency of conversion and use of wood fuel is typically low due to poor technologies for production of charcoal, and inefficient woodstoves (see Indicator 18). Extensive extraction of fuel wood for both commercial and subsistence purposes is a driver of woodland degradation throughout Ethiopia. Fuel wood extraction is most prominent surrounding urban areas, as urban areas have high demand for fuel wood. The extent of biomass scarcity is exemplified by the long travel distances currently required for wood collection.

Projection of fuelwood demand and supply

The present trend shows that both rural and urban demand for wood energy has increased and is expected to increase due to the growing populations and macro-economic changes. The projected sustainable fuelwood supply is estimated to reach 8.6 million m³ in 2030 (Bekele 2011; Indufor 2016; Ministry of Environment, Forest and Climate Change [MEFCC] 2018a). The future wood fuel / feedstocks projections (2015-2030) of demand and supply indicate that demand during the years 2020, 2025 and 2030 will still greatly exceed the supply (Table 4.12; Figure 4.5).

Figure 4.5. Projection of fuelwood demand, 2015-2035



Source: Adapted/drawn from that data of Kassa and Ewnetu 2014.

Table 4.12. Future demand and supply projections (2015-2030) of wood fuel / feedstocks (firewood and charcoal) from plantations and natural forests

Wood fuel source	2020	2025	2030
Wood fuel (firewood/charcoal) demand from natural forests and plantations (1 000 m³)	153 441	176 528	203 015
Wood fuel (firewood/charcoal) supply from natural forests and plantations (1 000 m³)	10 243	10 619	10 996
Supply rate (%) over demand	6.7	6	5.4

Source: Adapted from Bekele 2011.

4.3.6 Conclusions and recommendations

Synthesis of the findings

The annual volume of wood harvested for wood fuel was around 120.4 million m^3 of roundwood equivalent in 2015, and in 2035 it will reach 157.79 million m^3. Currently, more than 90 per cent of the domestic supplies of fuel wood come from diverse sources such as natural high forests and woodlands, industrial plantations and private forests (trees outside forests including woodlots). To fill the indicated gap, there is a great need to establish additional fuelwood plantations across the country.

As regards biogas, its use has greatly reduced the use of firewood contributing to improvement in the forest coverage. However, quantified values are not available.

Practices and policies to improve sustainability

The Ethiopian forest policy and strategy (2007) and the recent forest proclamation number 1076/2018 encourages farmers / tree growers, communities and private investors (in public private partnerships) to grow, manage and utilize forests for their different products including fuel wood and charcoal (FDRE 2018). It is believed that this policy provision will help to bring fuelwood plantations that will contribute to filling the fuelwood demand gap in the country. The additional land requirement needed to establish fuelwood plantations can be minimized by using fast-growing and high-yielding tree/shrub species such as *Eucalyptus*, *Acacia decurrens*, with appropriate stand management.

Promoting and developing woodlots and agroforestry can be guided by identifying which multi-purpose tree species are most appropriate for which agroecological zone. Once this knowledge is available, a site-species matching should be carried out by the appropriate extension service provider for each parcel of land prior to planting. This site-species evaluation should be conducted prior to delivery of seedlings from the nursery. Thereafter, the land holders should be informed about why they are planting these different tree species and they should be trained in their management. Thus, extension services play a key role in assessing the land and creating awareness regarding the purpose of the specific trees that were planted in the respective areas (MEFCC 2018b).

According to MEFCC (2018b), the strategy for improved and sustainable charcoal production from agriculture and forest by products will be:

- Establish market regulation and improve law enforcement to reduce the availability of unsustainable, illegal wood fuel on the market;
- Increase the supply of sustainable wood fuel production through promoting woodlots and sustainable management of natural forests;
- Provide incentives for the establishment and management of woodlots (could be done in the context of REDD+).

The residues from industrial plantations will be used as a sustainable solid biomass source. Moreover, it is important to use other energy alternatives such as biogas, hydropower, solar, wind, geothermal and other non-wood biomass energy sources in order to reduce pressure on existing forest resources of the country.

Future monitoring
In Ethiopia, although a significant proportion of harvested wood is used for energy purposes (wood fuel, charcoal, etc.), data are only available on forest cover, wood supply, wood demand and consumption. It is very difficult to get data by cubic metre per hectare per year and in tons per hectare per year both for the supply and demand. Therefore, monitoring of this indicator in the future would be important in Ethiopia, along with Indicators 17 and 22, in order to assess whether statistics on the use of wood fuel match the shares of energy coming from traditional use of biomass.

4.3.7 References

Bekele, M. (2011). Forest plantations and woodlots in Ethiopia. *African Forest Forum Working Paper Series* 1, 12.

Ethiopia Environment, Forest and Climate Change Commission (2019). *Ethiopia Bamboo Development Strategy and Action Plan* (2019-2030).

Federal Democratic Republic of Ethiopia (2018). A proclamation to provide for the public-private partnership. *Federal Negarit Gazetta of the Federal Democratic Republic of Ethiopia*, No. 1076. Addis Ababa.

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

Food and Agriculture Organization of the United Nations (2018). *Year Book of Forest Products 2016.* Rome.

Food and Agriculture Organization of the United Nations (2018). *Terms and Definitions, Global Forest Resources Assessment 2020.* Rome.

Food and Agriculture Organization of the United Nations (2019). *Year Book of Forest Products 2017.* Rome.

Forest Policy (2007). *Forest Development, Conservation and Utilization Policy and Strategy*. Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development. Addis Ababa.

INDUFOR (2016). *Commercial Plantation Forestry Investment Plan Ethiopia Study INDUFOR*. Final Report.

Kassa, M. and Ewnetu, Z. (2014). *The Importance of Forestry in Ethiopia and the Need for Investing in the Sector to Meet National Goals and International Commitments*. Unpublished report.

Ministry of Environment, Forest and Climate Change (2016). *The Contribution of Forests to National Income in Ethiopia and Linkages with REDD+*, Executive summary. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2017). *Ethiopia Forest Sector Review*. *Technical Report. Focus on commercial forestry and industrialization.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018a). *National Forest Sector Development Program, Ethiopia. Volume I: Situation Analysis.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018b). *National Forest Sector Development Program, Ethiopia. Volume II: Program Pillars, Action Areas and Targets.* Addis Ababa.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey*. National Biogas Programme of Ethiopia. Addis Ababa.

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

4.4.1 Researcher(s)

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4.4.2 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.

4.4.3 Measurement unit(s)

Emissions of $PM_{2.5}$, PM_{10}, NO_X, sulphur dioxide and other pollutants in 1) mg/ha, mg/MJ, and as a percentage; 2) mg/m^3 or ppm; 3) mg/MJ; 4) mg/MJ

4.4.4 Overall methodology of the implementation

The spreadsheet-based life cycle analysis (LCA) tool, developed by the Institut für Energieund Umweltforschung Heidelberg (IFEU) in partnership with GBEP and UNEP, was used to quantify the toxic, non-greenhouse gas and particulate emissions of each stage of the value chain: feedstock production and collection, processing, transport of primary or transformed resources, storage, and final uses by the consumers. The spreadsheet includes sulphur dioxide, nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, PM_{10}, dust and ammonia. Emission factors are based on international literature and life cycle analysis databases and adapted to Ethiopia. Sources of information are similar as for Indicator 1.

4.4.5 Key findings

Numerical results are presented below. Analysis is provided in the following section.

BIOGAS

Figure 4.6. Summary of life cycle SO_2 emissions from using biogas compared to traditional wood cooking during collection, transport, processing and use

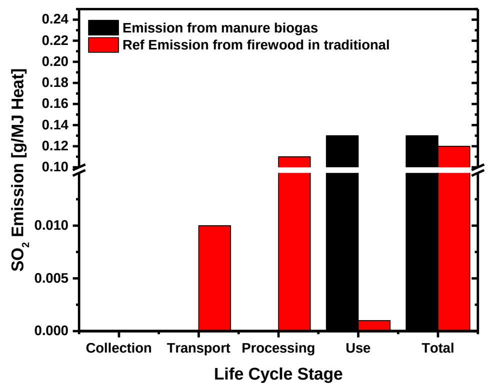

Figure 4.7. Summary of life cycle CO emissions from using biogas compared to traditional wood cooking and LPG during collection, transport, processing and use

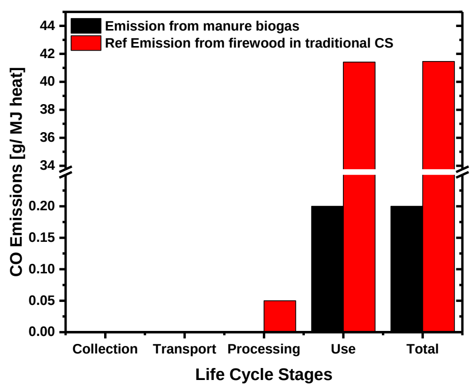

Figure 4.8. Summary of life cycle PM_{10} emissions from using biogas compared to traditional wood cooking during collection, transport, processing and use

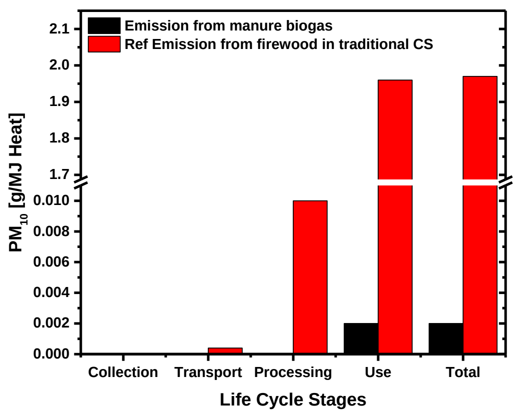

Table 4.13. Comparison of summary of toxic and non-greenhouse gas emissions from the use of biogas with firewood used in traditional cookstove and LPG

Toxic and non-GHG emission	Life cycle stage	Emission from manure biogas (g/MJ heat)	Reference emission from traditional wood (open fires) (g/MJ heat)	Difference in emissions (biogas over traditional wood (open fires))	
				in percent (%)	Per functional unit (g/MJ heat)
SO_2	Collection	0	0	0	0
	Transport	0	0.01	-100	-0.01
	Processing	0	0.11	0	0
	Use	0.13	0.001	+12900	+0.13
	Total	0.13	0.12	+9	+0.01
NO_x	Collection	0	0	-	-
	Transport	0	0.01	-100	-0.10
	Processing	0	0.12	0	0
	Use	0.26	0.07	+271	+0.19
	Total	0.26	0.19	+36	+0.07
CO	Collection	0	0	-	-
	Transport	0	0.001	-100	-0.02
	Processing	0	0.05	0	0
	Use	0.20	41.41	-99.5	-41.26
	Total	0.20	41.46	-100	-41.26
NMVOC	Collection	0	0	-	-
	Transport	0	0.003	-100	-0.003
	Processing	0	0.10	-100	-0.10
	Use	0.04	6.67	-99.5	-6.63
	Total	0.04	6.77	-99	-6.64
PM_{10}	Collection	0	0	-	-
	Transport	0	0.0004	-100	-0.003
	Processing	0	0.01	-100	-0.01
	Use	0.002	1.96	-99.9	-1.96
	Total	0.002	1.97	-99.9	-1.96
Dust	Collection	0	0	--	-
	Transport	0	0.001	-100	-0.001
	Processing	0	0.01	-100	-0.01
	Use	0.002	201.57	-100	-201.57
	Total	0.002	201.57	-100	-201.57
NH_3	Collection	0	0	-	-
	Transport	0	0.000003	-100	-0.00004
	Processing	0	0.000192	-100	-0.000192
	Use	0	0	-	-
	Total	0	0.000195	-100	-0.000195

FIREWOOD

Figure 4.9. Summary of life cycle SO_2 emissions from using firewood in improved cookstoves, compared to traditional wood cooking and LPG during collection, transport, processing and use

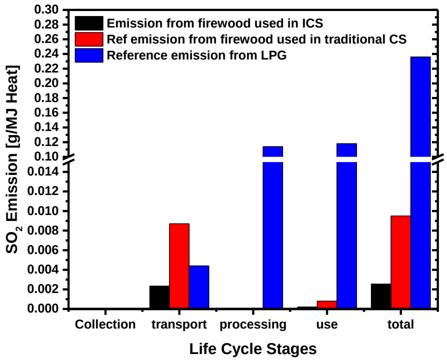

Figure 4.10. Summary of life cycle CO emissions from using firewood in improved cookstoves, compared to traditional wood cooking and LPG during collection, transport, processing and use

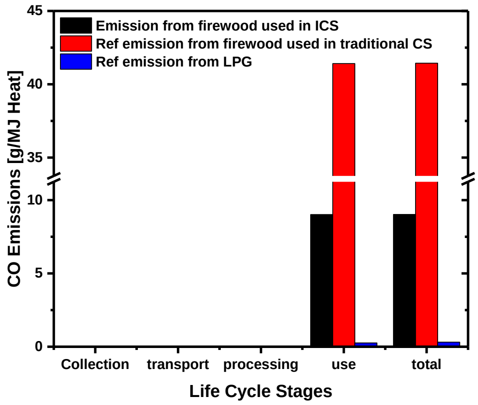

Figure 4.11. Summary of life cycle PM_{10} emissions from using firewood in improved cookstoves, compared to traditional wood cooking and LPG during collection, transport, processing and use

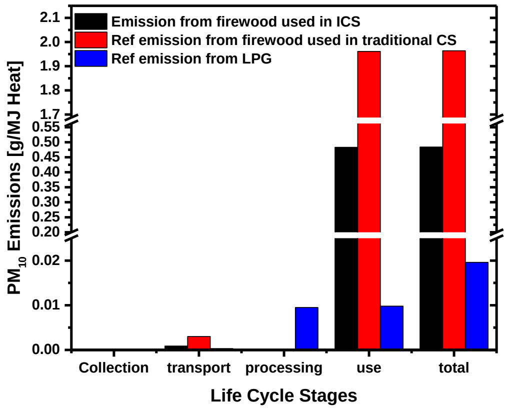

Table 4.14. Comparison of summary of toxic and non-greenhouse gas emissions from the use of firewood in improved cookstoves and in traditional wood (open fires)

Toxic and non-GHG emission	Life cycle stage	Emission from firewood used in ICS (g/MJ heat)	Reference emission from firewood used in traditional wood (open fires) (g/MJ heat)	Reference emission from LPG (g/ MJ heat)	Difference in emissions (Firewood in ICS over traditional wood (open fires)		Difference in emissions (Firewood in ICS over LPG)	
					in percent (%)	Per functional unit (g/MJ heat)	in percent (%)	Per functional unit (g/MJ heat)
SO_2	Collection	0	0	0	-	-	-	0
	Transport	0.002336	0.0087	0.0044	-73.1	-0.006	-46.9	-0.002
	Processing	0	0	0.114	-	-	-100	-0.11
	Use	0.00021	0.0008	0.118	-73.8	-0.0006	-99.8	-0.12
	Total	0.002546	0.0095	0.236	-73.2	-0.007	-98.9	-0.23
NO_x	Collection	0	0	0	-	-	-	0
	Transport	0.027985	0.104	0.004	-73.1	-0.08	599.6	0.02
	Processing	0	0	0.118	-	-	-100	-0.12
	Use	0.021008	0.069	0.403	-69.6	-0.05	-94.8	-0.38
	Total	0.048993	0.173	0.525	-71.7	-0.12	-90.7	-0.48
CO	Collection	0	0	0		0	-	0
	Transport	0.006419	0.024	0.001	-73.3	-0.02	541.9	0.005
	Processing	0	0	0.045	-	-	-100	-0.05
	Use	9.012605	41.412	0.262	-78.2	-32.4	3339.9	8.75
	Total	9.019024	41.436	0.308	-78.2	-32.4	2828.3	8.71
NMVOC	Collection	0	0	0	-	-		0
	Transport	0.002647	0.01	0.003	-73.5	-0.0074	-11.8	-0.0004
	Processing	0	0	0.095	-	-	-100	-0.1
	Use	1.84874	6.667	0.137	-72.3	-4.8	1249.4	1.71
	Total	1.85139	6.677	0.234	-72.3	-4.8	691.2	1.62
PM_{10}	Collection	0	0	0	-	-		0
	Transport	0.00087	0.003	0.0003	-71	-0.002	190	0.0006
	Processing	0	0	0.0095	-	-	-100	-0.01
	Use	0.48319	1.961	0.0098	-75.4	-1.5	4830.5	0.47
	Total	0.48406	1.964	0.0196	-75.4	-1.5	2369.7	0.46
Dust	Collection	0	0	0	-	-		0
	Transport	0.00104	0.00388	0.00084	-73.2	-0.003	23.8	0.0002
	Processing	0	0	0.01133	-	-	-100	-0.01
	Use	53.99	201.569	0.0121	-73.2	-147.6	446098.3	53.98
	Total	53.99	201.573	0.0121	-73.2	-147.6	446098.3	53.98
NH_3	Collection	0	0	0	-	-	-	0
	Transport	0.00001	0.000042	0.000002	-76.2	0	400	0.00001
	Processing	0	0	0.000192	-	-	-100	-0.0002
	Use	0	0	0.000195			-100	-0.0002
	Total	0.00001	0.000042	0.000389	-76.2	0	-97.4	-0.0004

Note: ICS = improved cookstoves

CHARCOAL

Figure 4.12. Summary of life cycle SO_2 emissions from using charcoal in improved cookstoves, compared to traditional wood cooking and LPG during collection, transport, processing and use

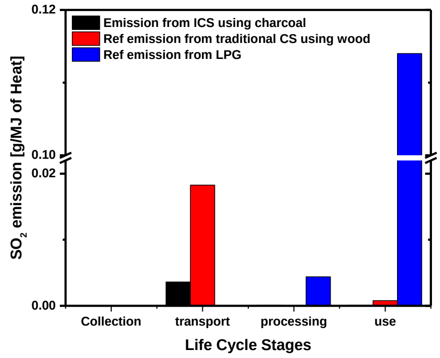

Figure 4.13. Summary of life cycle CO emissions from using charcoal in improved cookstoves, compared to traditional wood cooking and LPG during collection, transport, processing and use

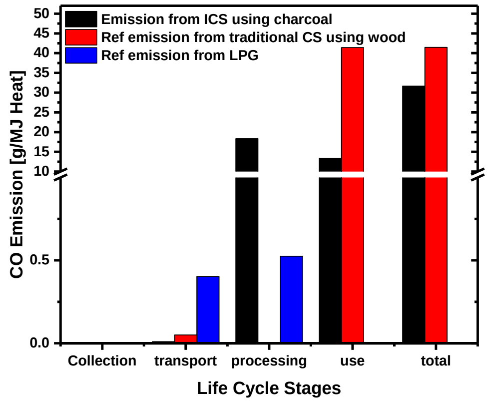

Figure 4.14. Summary of life cycle PM_{10} emissions from using charcoal in improved cookstoves, compared to traditional wood (open fires) and LPG during collection, transport, processing and use

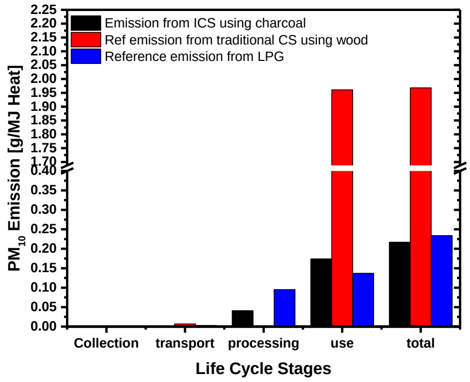

Table 4.15. Comparison of toxic and non-greenhouse gas emissions from the use of charcoal in improved cookstoves, traditional wood (open fires) and LPG

Toxic non-GHG emission	Life cycle stage	Emission from ICS using charcoal (g / MJ heat)	Reference emission from traditional wood (open fires) using wood (g / MJ heat)	Reference emission from LPG (g/ MJ heat)	Difference in emissions (charcoal in ICS over traditional wood (open fires))		Difference in emissions (charcoal in ICS over LPG)	
					In percent (%)	Per functional unit (g / MJ heat)	In percent (%)	Per functional unit (g / MJ heat)
SO_2	Collection	0	0	0	-	0	-	0
	Transport	0.00361	0.01828	0	-80.3	-0.01	-	0.004
	Processing	0.00008	0	0.0044	-	0.00008	-98.2	-0.004
	Use	0.00008	0.00078	0.114	-89.7	-0.0007	-99.9	-0.11
	Total	0.00377	0.01906	0.118	-80.2	-0.02	-96.8	-0.11
NO_x	Collection	0	0	0	-	0	-	0
	Transport	0.043	0.219	0.236	-80.4	-0.18	-81.8	-0.19
	Processing	0.005	0	0	-	0.005	-	0.005
	Use	0.015	0.069	0.004	-78.3	-0.05	275	0.01
	Total	0.064	0.288	0.118	-77.8	-0.22	-45.8	-0.05
CO	Collection	0	0	0	-	0	-	0
	Transport	0.01	0.05	0.403	-80	-0.04	-97.5	-0.39
	Processing	18.34	0	0.525	-	18.34	3393.3	17.82
	Use	13.32	41.41	0	-67.8	-28.09	-	13.32
	Total	31.67	41.46	0.001	-23.6	-9.79	3166900	31.67
NMVOC	Collection	0	0	0	-	0	-	0
	Transport	0.004	0.021	0.045	-81	-0.02	-91.1	-0.04
	Processing	7.62	0	0.262	-	7.62	2808.4	7.36
	Use	0.85	6.67	0.308	-87.3	-5.82	176	0.54
	Total	8.47	6.69	0	26.6	1.78	-	8.47
PM_{10}	Collection	0	0	0	-	0	-	0
	Transport	0.001	0.007	0.003	-85.7	-0.006	-66.7	-0.002
	Processing	0.041	0	0.095	-	0.041	-56.8	-0.05
	Use	0.174	1.961	0.137	-91.1	-1.79	27	0.04
	Total	0.217	1.968	0.234	-89	-1.751	-7.3	-0.017
Dust	Collection	0	0	0		0	-	0
	Transport	0.002	0.008	0	-75	-0.006	-	0.002
	Processing	2.5	0	0.0003	-	2.5	833233.3	2.5
	Use	0.41	201.57	0.0095	-99.8	-201.16	4215.8	0.4
	Total	2.91	201.58	0.0098	-98.6	-198.67	29593.9	2.9
NH_3	Collection	0	0	0	-	0	-	0
	Transport	0.00002	0.00009	0.0196	-77.8	-0.00007	-99.9	-0.02
	Processing	0	0	0	-	0	-	0
	Use	0	0	0.00084	-	0	-100	-0.0008
	Total	0.00002	0.00009	0.01133	-77.8	-0.00007	-99.8	-0.01

Note: ICS = improved cookstoves

4.4.6 Conclusions and recommendations

BIOGAS

Synthesis of the findings

Generally, the biogas pathway generates significantly greater amounts of sulphur dioxide and nitrogen oxides when compared with firewood and charcoal used in improved cookstoves. This shows a strong need for improvement of the quality of the biogas through upgrades. Use of biogas emits less of the lethal toxic carbon monoxide when compared to firewood and charcoal burned in any of the cookstoves. Emission of nitrogen oxides as well as ammonia can be minimized by maintaining the carbon-to -nitrogen ratio within the optimal range (20:1 to 30:1) required for efficient anaerobic digestion (Adelekan 2012). Optimal carbon-to-nitrogen can be maintained by mixing the manure substrate with easily digestible and abundant biomass resources.

The non-greenhouse gas emissions should be completely removed or transformed into benign by-products. For this, it is essential to trace and quantify their presence during collection, transport, processing and use. The major non-greenhouse gas emissions arise from the major elemental constituents of the cattle manure (carbon, hydrogen, oxygen, nitrogen and sulphur). There is high nitrogen content in the faeces and urine of dairy cattle which ranges from 10-17 and 4-10 gram, respectively, in each fresh kilogram of weight (Sommer *et al.* 2013). Specifically, the dairy manure can contain about 39.1, 4.6, 26.7, 0.83, 0.25 and 0.99 per cent of carbon, hydrogen, oxygen, nitrogen, sulphur and chlorine. The molecular constituents are methane (55-80 per cent), CO_2 (20-45 per cent) and negligible traces of hydrogen and hydrogen sulphide (Dahiya *et al.* 1986). The major oxidative high energy yielding elemental constituents are carbon and hydrogen.

Oxidation of carbon yields 15 times more energy than the combustion of sulphur while hydrogen oxidizes by releasing 10 times more energy than that of sulphur. Simple molecules and compounds of the rest are considered as impurities and should in some way be removed or minimized via pretreatment of the substrate or upgrade of the biogas. Water in the biogas should be extracted using for example activated carbon. The noxious odor dihydrogen sulphide can be removed by methods which either oxidize it to elemental sulphur or to sulphate biologically or chemically (Sommer, Ward and Leahy 2013). It is also important to scrutinize how the non-greenhouse gas emissions of biogas fare when compared to its reference cases in each of the life cycle stages. Biogas fares better in reduced emission of the non-greenhouse gas emissions in overwhelming cases of the life cycle stages.

Practices and policies to improve sustainability

It is recommended to do cookstove improvement research, as the use stage is the life cycle stage that generates significant amounts of toxic emissions such as carbon monoxide. In this regard, the ongoing National Biogas Programme and those supported by NGOs such as SNV can play a decisive role in the biogas upgrade research and its use in more improved cookstoves. Research institutes should also have major research programmes in this regard.

Future monitoring

Future research and development activities should widen the scope of this life cycle analysis by including emissions from enteric fermentation. Systematic, comprehensive and reliable inventory database of the toxic, non-greenhouse gas and particulate type emissions from all the life cycle stages of biogas should be established and updated regularly. It is also recommended to include the impact assessment and interpretation phases of life cycle analysis so that the results can be understood in light of comprehensive impact categories.

FIREWOOD

Synthesis of the findings
The solid biomass pathway emits most of the toxic, non-greenhouse gas and particulate emissions during the use life cycle stage and also during transport. As a result, improved cookstove innovations are indispensable to bring a significant reduction in these emissions. One of the reasons for increased emissions of carbon monoxide and ammonia is the combustion of solid biomass with high moisture content, which could have been reduced by allowing the biomass to dry in the open air.

Practices and policies to improve sustainability
The improved cookstove projects of the Environment, Forests and Climate Change Commission of Ethiopia and particularly those of NGOs such as GIZ should be given priority. There is also a need to reduce the transport distance by optimizing the supply chain of firewood.

Future monitoring
The inclusion of the smaller particulates $PM_{2.5}$ in the life cycle analysis tool used for the analysis would be an important addition, given the toxicity of these particles for health.

Moreover, future research and development activities should widen the scope of this life cycle analysis to at least cradle-to-grave by including emissions from tree planting and growing. A systematic, comprehensive and reliable inventory database of the toxic, non-greenhouse gas and particulate type emissions from all the life cycle stages of the biomass should be established and updated regularly. Similar to the biogas pathway, in this one also it is recommended to include the impact assessment and interpretation phases of life cycle analysis so that the results can be understood in light of comprehensive impact categories.

CHARCOAL

Synthesis of the findings
Most of the emissions of sulphur dioxide, nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, PM_{10} and dust using charcoal in improved cookstoves occur during the charcoal processing and use life cycle stages. Particularly dust and non-methane volatile organic compounds dominate emissions of the use life cycle stage. The excessive emissions during charcoal processing stages arise mainly due to the inefficient technology used. The traditional earth-mound kilns use internal heating with a difficult-to-control combustion process (insulation and control of air flow) resulting in increased emissions of sulphur dioxide, nitrogen oxides and carbon monoxide (Emrich 1985).

Practices and policies to improve sustainability
Innovating the charcoal processing and use life cycle stages and finding regulated ways of implementing improvements are crucial since these stages are the dominant contributors to the overall emissions of toxic, non-greenhouse gas and particulate types. Particularly, there is a strong need to find effective methods to mitigate the high rate of carbon monoxide emission in the processing and use life cycle stages of the charcoal life cycle. This should start by decriminalizing charcoal making and promoting innovative, optimal and sustainable means of charcoal making. Generally, prohibiting charcoal making while it is supporting the livelihoods of many rural youth does not make sense. This has only exacerbated degradation of the woodland in addition to making the charcoal production a sinful act and one of the lowest-priority areas for innovation research.

Innovation of the charcoal-making process is complex and calls for close partnership between the Ethiopian government (the forest, environment and energy sectors), rural youth and research institutes. Application of blockchain technology could be one of the most effective ways to prove the legality and sustainability of charcoal manufacturing. In this regard, the Ministry of Innovation and Technology of Ethiopia initiated a programme that tests the use of blockchain technology in tracking and certifying agri-products, in which the charcoal production process can be included.

Future monitoring

The inclusion of the smaller particulates $PM_{2.5}$ in the life cycle analysis tool used for the analysis would be an important addition, given the toxicity of these particles for health.

Moreover, future research and development activities should also widen the scope of this life cycle analysis to at least cradle-to-grave by including emissions from tree planting, growing and harvesting. A systematic, comprehensive and reliable inventory database of the toxic, non-greenhouse gas and particulate type emissions from all the life cycle stages of charcoal should be established and updated regularly. Similar to the biogas pathway, in this one also it is recommended to include the impact assessment and interpretation phases of life cycle analysis so that the results can be understood in light of comprehensive impact categories.

4.4.7 References

Adelekan, B.A. (2012). Potentials of Selected Tropical Crops and Manure as Sources of Biofuel. In: S. Kumar (ed.). *Biogas*. Intech, Croatia.

Bhattacharya, S.C., Albina D.O. and AbdulSalam, P. (2002). Emission factors of wood and charcoal-fired cookstoves. *Biomass and Bioenergy* 23, 453-469.

Chidumayo, E. and Gumbo, J.D. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development* 17, 86-94.

Dahiya, R.P., Chand, A., Sharma, S.C. and Dayal, M. (1986). Investigations of seeded combustion products of biogas/ air – O_2 systems. *Energy Conversions Management* 26(2), 253-258.

Daniel, A. (2016). *Geometrical Optimization of Biomass Cook Stove for Efficient Utilization of Energy: (In case of Tikikil Stove*). A thesis research submitted in partial fulfillment of the requirement for the degree of Master of Science in thermal engineering. Addis Ababa Institute of Technology, Addis Ababa University.

Emrich, W. (1985). *Handbook of Charcoal Making, The Traditional and Industrial Methods*. 7(E), Springer Science.

Ethiopia Environment, Forest and Climate Change Commission (2019). *Distribution Status of Improved Cookstoves in Ethiopia*. Unpublished report. Addis Ababa

Globales Emissions-Modell Integrierter Systeme (GEMIS) (2014). Version 4.9. http://www.iinas.org/gemis-download-de.html.

Hansmann, C., Stingl, R., Prieto, O.G., Lopez, C.B. and Resch H. *et al.* (2008). High-frequency energy-assisted vacuum drying of fresh E. Globulus. *Drying Technology* 26(5), 611-616.

Mamuye, F., Lemma, B. and Woldeamanuel, T. (2017). Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia. *Sustainable Environment Research* 28, 32-38. https://doi.org/10.1016/j.serj.2017.09.003.

SNV Netherlands Development Organisation, Strengthening Enabling Environment in Clean Cooking Sector (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia. Strengthening the Enabling Environment for Clean Cooking Project*, Final Report.

Sommer, S.G., Christensen, M.L., Schmidt, T. and Jensen, L.S. (eds.) (2013). *Animal Manure Recycling, Treatment and Management*.

Sommer, S.G., Ward, Alastair J. and Leahy, J. J. (2013) Bioenergy Production. In: Sommer, S.G., Christensen, M.L., Schmidt, T. and Jensen, L.S. (eds.), *Animal Manure Recycling, Treatment and Management.*

Tumwesige, V., Fulford, D. and Davidson, G.C. (2014). *Biogas Appliances in Sub-Sahara Africa*.

4.5 Indicator 5. Water use and efficiency

4.5.1 Researcher(s)

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4.5.2 Definition

(5.1) Water withdrawn from nationally determined watersheds(s) for the production and processing of bioenergy feedstocks, 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 feedstocks per unit of bioenergy output, disaggregated into renewable and non-renewable water sources

4.5.3 Measurement unit(s)

(5.1a) Percentage
(5.1b) Percentage
(5.2) m^3/MJ or m^3/kWh or m^3/tone for feedstock production phase if considered separately

4.5.4 The overall methodology of the implementation

The analysis has focused on the study of the current situation related to water supply, demand, and uses, and the characterization of water basins in the country. Water resources were estimated using FAO AQUASTAT while for overall information concerning water availability and water demand, national reports were consulted.

As regards solid biomass, all types of plantations of feedstock for solid biomass production are mostly rain fed in Ethiopia; therefore, water consumption for solid biomass cultivation is mainly composed of green water.

As regards biogas, the water used by biodigesters is calculated using secondary data. Since cow dung is a residue, the water used to produce dung does not need to be considered in the indicator.

4.5.5 Key findings

Overall water resources in Ethiopia
Ethiopia is endowed with a substantial amount of water resources but very high hydrological variability.

The surface water resource potential is impressive, the proper use of surface water is not effective and there is no such development on the use. But there is ineffective use and little developed on the use of surface water for different purposes. The country has 12 major river basins, which form four major drainage systems:

- The Nile basin (including Abbay or the Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara and Mereb) covers 33 per cent of the country and drains the northern and central parts westwards.
- The Rift Valley (including Awash, Denakil, Omo-Gibe and Central Lakes) covers 28 per cent of the country and consists of a group of independent interior basins extending from Djibouti in

the north to the United Republic of Tanzania in the south, with nearly half of its total area being located in Ethiopia.
- The Shebelle-Juba basin (including Wabi-Shebelle and Genale-Dawa) covers 33 per cent of the country and drains the southeastern mountains towards Somalia and the Indian Ocean.
- The North-East Coast (including the Ogaden and Gulf of Aden basins) covers 6 percent of the country.

Most of the rivers in Ethiopia are seasonal, and there are almost no perennial rivers below 1,500 m altitude. Around 70 percent of the total runoff takes place during June-September. The dry season flow originates from springs that provide base flows for small-scale irrigation.

The groundwater potential of the country is not known with any certainty, but so far only a small fraction of the groundwater has been developed or used. It is, however, more easily available than surface water in arid areas and supplies about 80 per cent of the existing drinking water sources (Ethiopian Environmental Protection Authority [EPA] and United Nations Environment Programme [UNEP] 2008). Traditional wells are widely used by nomads and other rural areas.

Internal renewable surface water resources are estimated at 120,000 million m^3/year, and renewable groundwater resources are around 20,000 million m^3/year, but 18,000 million m^3/year is considered to be overlap between surface water and groundwater, which gives a value of total internal renewable water resources of 122,000 million m^3/year (Table 4.16).

Table 4.16. Water resource

Renewable freshwater resources	Year	Magnitude	Rate/ Unit
Precipitation (long-term average)	-	848	mm/yr
	-	936 400	million m^3/yr
Internal renewable water resources (long-term average)	-	122 000	million m^3/yr
Total renewable water resources	-	122 000	million m^3/yr
Dependency ratio	-	0	%
Total renewable water resources per inhabitant	2015	1 227	m^3/yr
Total dam capacity	2015	31 484	million m^3

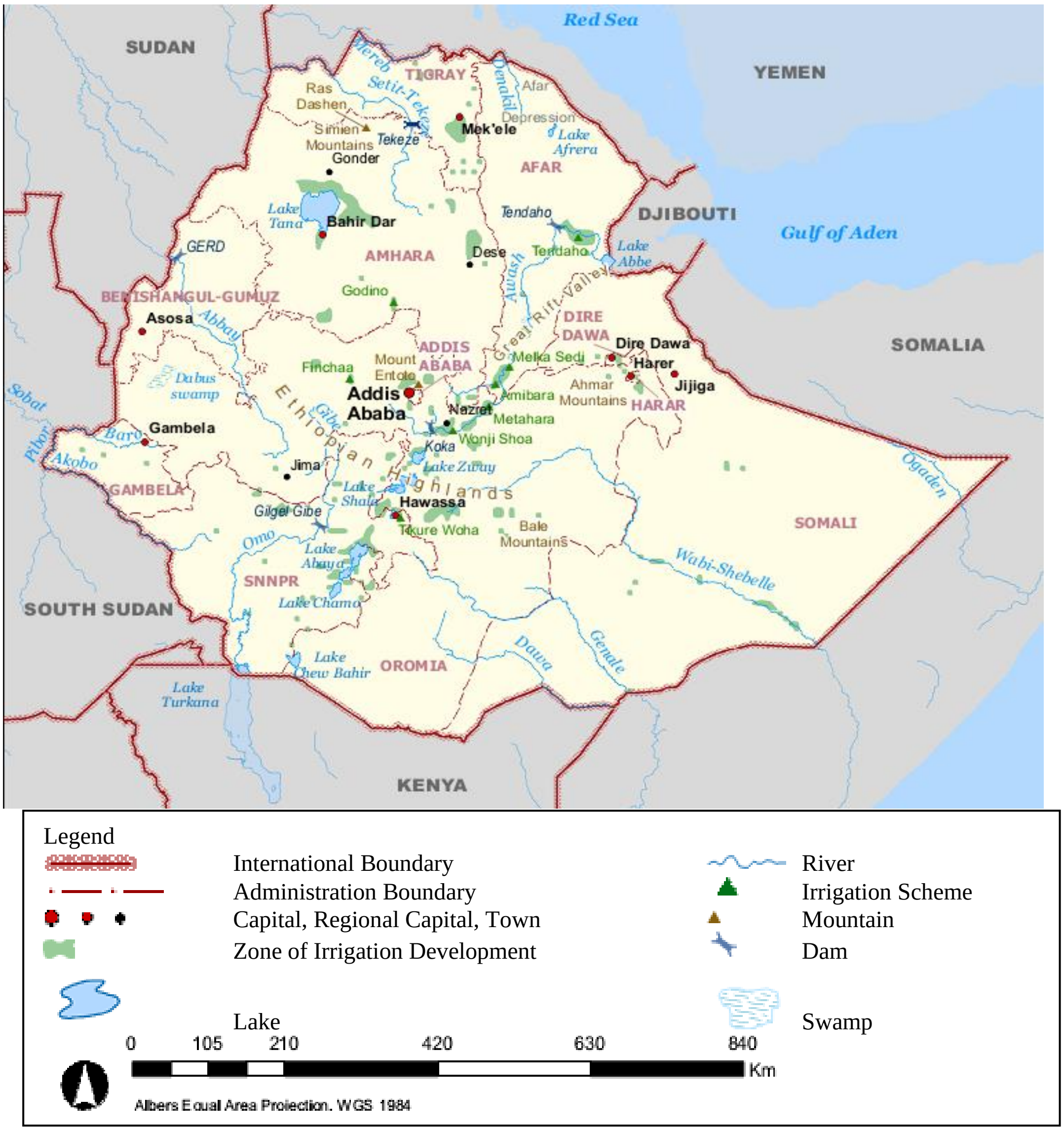
Source: FAO 2016.

External water resources are null and the surface water leaving the country is estimated at 96,500 million m^3/year (Figure 4.18), of which:

- 64,600 million m^3/year flows into Sudan through the Blue Nile and its tributaries (52,600 million m^3/year), the Atbara river (4,370 million m^3) and the Setit-Tekeze river (7,630 million m^3/year);
- 13,000 million m^3/year flows into South Sudan through the Baro and Akobo rivers forming the Sobat river;
- 8,200 million m^3/year flows into Somalia through the Genale and Dawa rivers forming the Juba river (5,900 million m^3/year) and the Shebelle river (2,300 million m^3/year);
- 10,000 million m^3/year flows into Kenya through the Omo River into Lake Turkana; and
- 700 million m^3/year flows into Eritrea.

These important run-off flows to other countries have resulted in Ethiopia being called the “Water Tower of East Africa”.

Map 4.6. Ethiopian surface water leaving the country



Source: FAO 2016.

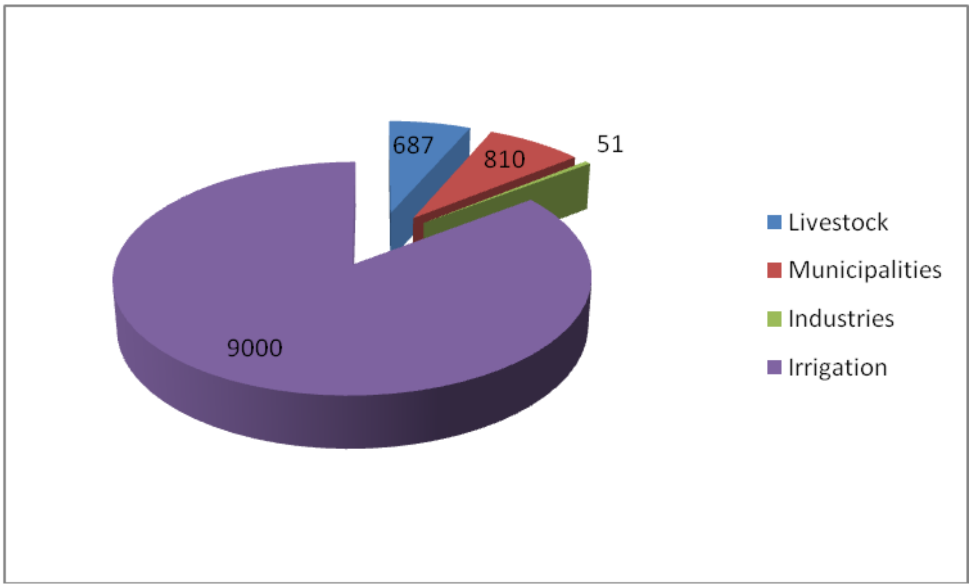
Main withdrawals of water

Agriculture is by far the main water-withdrawing sector (Figure 4.15). Both irrigated and rainfed agriculture are important in the Ethiopia economy. Nevertheless, virtually all food crops (97 per cent) in Ethiopia come from rainfed agriculture, with the irrigation subsector accounting for only about 3 per cent of food crops. Industrial crops such as sugar cane, cotton, and fruit are mostly irrigated (FAO 2015). Urban and peri-urban irrigation is not significant in terms of area coverage and production, but the traditional irrigation practiced around Addis Ababa plays an important role in supplying vegetables to the Addis Ababa market. The use of irrigation technology, although currently not widespread, can reduce risk and improve production (FAO 2015). Based on the total irrigated area, cropping pattern and calendar, annual agricultural water withdrawal was an estimated 5,200 million m^3 in 2002, while municipal and industrial water withdrawals were an estimated 330 million m^3 and 20 million m^3 respectively (FAO AQUASTAT 2016).

Agricultural water withdrawal in 2016 was an estimated 9,000 million m³, showing a large increase from 2002. This seems to be underestimated given the large increase or irrigated areas and the changing in irrigated crops. The huge livestock population withdrew an estimated 687 million m³ in 2010 (European Union [EU] 2011). Industrial demand was an estimated 51 million m³, and municipal water withdrawal was 810 million m³, in 2005.

Groundwater is mostly used for drinking supply. It represents around 70 per cent of rural water supply and plays a major role in several of the largest cities – Addis Ababa, Dire Dawa, Mekelle and Harar – and a number of medium-sized towns. Groundwater use in irrigation is only at a pilot scale for now, but plans to develop it are being studied, and shallow groundwater wells are being constructed by farmers in some areas (Ethiopia Ministry of Water Resources [MoWR] 2011).

Figure 4.15.Water withdrawal by sector



Source: FAO 2016.

Table 4.17. Water use by sector

Water withdrawal	Year	Magnitude	Rate/Unit
Total water withdrawal	2016	10 548	million m³/yr
Irrigation	2016	9 000	million m³/yr
Livestock	2010	687	
Municipalities	2005	810	million m³/yr
Industry	2005	51	million m³/yr
Per inhabitant	2015	106	m³/yr
Surface water and groundwater withdrawal (primary and secondary)	2016	10 548	million m³/yr
As % of total renewable water resources	2016	8.6	%
Non-conventional source of water			
Production municipal wastewater	2014	226[(1)]	million m³/yr
Treated municipal wastewater	2014	0.8[(1)]	million m³/yr
Direct use of treated municipal wastewater		-	million m³/yr
Direct use of agricultural drainage water		-	million m³/yr
Desalinated water production		-	million m³/yr

[(1)] This refers to the nine cities only.
Source: FAO 2016.

Availability of water for biodigesters
Availability of sufficient water is a key factor limiting the pace of biogas expansion in Ethiopia. (Biruk 2010; Mengistu *et al.* 2015).

Availability of water is mainly area dependent, and in most parts of Ethiopia recurrent droughts have to be taken into consideration. Although a comprehensive national study of groundwater resources has not been conducted, some surveys suggest that there is ample groundwater potential in many parts of Ethiopia. Additionally, there are many locations where permanent rivers and streams flow in the highlands of Ethiopia.

Fetching water required to mix with the daily input of fresh dung in a 1 litre:1kg fresh dung ratio should not take more than 20 to 30 minutes. Many farm locations definitely meet this requirement, but many also do not. Careful and strict selection of the locations for the installation of biogas plants should help avoid disappointments (Netherlands Development Organisation [SNV] 2008).

Urine can be collected and used for feeding the biogas plant and replaces the daily amount of water required. However, the type of stable floor commonly used in Ethiopia does not allow for urine collection. The collections of urine will, however, be promoted, and rural households will be encouraged to voluntarily construct a low-cost stable floor suitable for urine collection (SNV 2008).

Besides the biogas digesters installed at the household level, digesters are installed around the condominium houses that were distributed to people by the government, some industries, universities, and other sectors. But there are no available data on how much water they consume and how much biogas energy they produce.

The average household biogas digester volume is 6 m^3, and the total amount of water used by all household biogas digesters is an estimated 273,057.42 m^3/yr for 22,166 household biodigester plants, of which 75 per cent are functional. The related average estimated biogas production is 1.17 m^3/day for a single biodigester and 19,450.66 m^3/day for the 22,166 household biodigester plants, of which 75 per cent are functional, equivalent to 7,099,492.73 m^3/year. Assuming that 22 MJ of thermal energy is generated from 1 m^3 of biogas, then 156,188,840.06 MJ of total thermal energy is generated in a year. Therefore, in the case of household biogas digesters in Ethiopia, the water withdrawn per unit of energy output is 0.006 m^3/kWh.

Table 4.18. Water withdrawals associated with biogas production in Ethiopia in 2016

Parameter	Value
Total actual renewable water resource in Ethiopia	122 000 million m^3/year
Total water requirements for operating biogas digesters	273 057 m^3/year
Total water withdrawals to operate biogas digester as a percentage of total actual renewable water resource	2.24%
Total biogas produced from biogas digesters	7 099 492 m^3/year
Total energy produced from biogas digesters	156 188 840 MJ
Volume of water withdrawal for biogas production per unit of energy output	0.0017 m^3/MJ

Source: Computation by the authors.

4.5.6 Conclusions and recommendations

Synthesis of the findings
Ethiopia has a high water potential for both groundwater and surface water, and total internal renewable water resources are 122,000 million m^3/year. Of this, renewable surface water is an estimated 120,000 million m^3/year, and renewable groundwater resources are around 20,000 million m^3/year; the rest (18,000 million m^3/year) is considered to be overlap between surface water

and groundwater. There is no external water resource, but 96,500 million m^3/year of surface water leaves to the neighbouring country.

The amount of water used by biogas digesters in the country is 273,057 m^3/year. The unavailability of water is an important factor contributing to the malfunction and non-function of the biodigesters.

Water is the main factor that limits the implementation and dissemination for biogas digester installation and efficiency. Therefore, it is suggested that to run a biogas digester efficiently, the time to reach the water body should be less than 30 minutes.

Practices and policies to improve sustainability
The Ethiopia Water Sector Policy, also known as the Federal Water Resource Management Policy, was issued in 1998. The objectives of this policy are sustainable use, protection and efficient use of water resources. The policy was legalized by the Ethiopia Water Resource Proclamation No. 197/2000, which is intended to be a more comprehensive and stronger version of the earlier Water Resources Utilization Proclamation No. 92/1994.

In 2007, the Ethiopia Council of Ministers approved the River Basin Councils and Authorities Proclamation (Proclamation No. 534/2007) to authorize the establishment of River Basin High Councils and River Basin Authorities for each of Ethiopia's major river basins. The Ethiopia Water Sector Policy focuses primarily on river basins as the fundamental planning unit and water resource management domain. Overall the water polices of Ethiopia are mainly focused on promoting national efforts towards efficient, equitable and optimum utilization of available water resources at the national level.

In the case of biogas digesters, there is a need to align the programme with Ethiopia's national water policies and strategies. It is also essential to consider the availability of water and the use of other water sources for the installed and future biodigesters. Urine is also another possibility; however, its use requires the construction of a simple floor for the collection of urine and its injection into the biogas plant. Therefore, there is a need for further research on the way to use urine to supplement water in water-unavailable areas.

Future monitoring
The water sectors monitoring and evaluation ranges from reports, field visits, and meetings by different agencies using standard formats. The Federal Ministry undertakes mid-term and annual review meetings with the respective Water Bureaus. But the filing and documentation system is weak. In the case of biogas digesters, in addition to the water availability check, there is a need to monitor the functionality of biogas digesters after the installation and to give consecutive training to users. Revising the programme and system based on water use and efficiency should be given consideration.

4.5.7 References

Biruk, T. (2010). *Assessment of the Potential and Challenges of Microfinance Institutions to Enable the Uptake of the Household Biogas in the National Biogas Program (NBP) of Ethiopia*. The University of Twente, the Netherlands.

Ethiopia Environmental Protection Authority and United Nations Environment Programme (2008). *Environment for Development. Ethiopia Environment Outlook*. Addis Ababa.

Ethiopia Ministry of Water Resources (2011). *Ethiopia: Strategic Framework for Managed Groundwater Development.* Addis Ababa.

European Union (2011). *Managing Water for Inclusive and Sustainable Growth in Ethiopia: Key Challenges and Priorities.* European Report on Development.

Food and Agriculture Organization of the United Nations (2015). *Ethiopia Irrigation Market Brief. Country Highlights.* Rome.

Food and Agriculture Organization of the United Nations (2016). AQUASTAT. http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/ETH-WR_eng.stm.

Lemelem, T. (2016). Biogas technology adaptation in rural Ethiopia: Its effect on the crisis of deforestation. *Journal of Energy Technologies and Policy* 6(1).

Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S. (2015). A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. *Renewable and Sustainable Energy* Reviews 48, 306-316. http://dx.doi.org/10.1016/j.rser.2015.04.026.

4.6 Indicator 6. Water quality

4.6.1 Researcher(s)

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4.6.2 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.

4.6.3 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 ha per year
(6.2) Pollutant loadings attributable to bioenergy processing effluent: pollutant levels in bioenergy processing effluent in mg/litre.

4.6.4 Overall methodology of the implementation

This indicator does not apply to solid biomass since no fertilizer is used to grow solid biomass used for energy purposes.

Published articles/book chapters found from internet research were used as references to compile relevant information on the environmental impacts of biogas digesters in Ethiopia. Although it is known that bioslurry from installed biogas digesters has been used as fertilizer in Ethiopia, indicator component 6.2 could not be reported due to a lack of published data on pollutant loading to waterways and bodies of water from biogas processing effluents.

4.6.5 Key findings

NATIONAL LEVEL

Water pollution is still mostly limited to urban and industrial areas, but soil salinization is directly linked to irrigated agriculture.

Erosion and sedimentation
Erosion is caused by natural factors, such as topography, torrential rains and wind. It is also caused by human activities, in particular deforestation for agriculture, charcoal, construction and mining, or by grazing, all due to unsustainable utilization and rapidly expanding human and livestock populations. Annual soil erosion amounts to about 1,900 million tons/year, impacting water, land and agricultural productivity (Awulachew, Erkossa and Namara 2010). Since the majority of the main rivers have their headwaters in the highlands of the country, their silt content is high. As a result, water bodies are silting up, especially in the Abbay basin (Mosello *et al.* 2015).

Sedimentation in dams, such as the Koka, Aba Samuel, Borkena and Gondar, has reduced their storage capacity. Water levels of natural lakes have decreased, in particular in Awasa, Abaya, Alemaya, Lange, Rudolf, Chew Bahir, Adele and Zway, and some lakes show signs of drying up. Finally, a number of rivers have changed their courses due to siltation, particularly during the rainy season, resulting in yearly flooding in the areas near the river banks. This is particularly the case of the Lower Awash River (Ethiopia Environmental Protection Authority [EPA] 2003; EPA 2008).

Water pollution
Water pollution is still limited to industrial, mining and urban areas (EPA 2012), but it is a growing problem in the Awash River Basin, due to major cities and industries in the Upper Basin. In the early 2000s, around 80 per cent of industries around Addis Ababa discharged their waste into nearby water bodies without any treatment. Tributaries of the Awash River around Addis Ababa and Nazareth are polluted (Ethiopia EPA 2003). Pollution has caused water hyacinth infestation in Lake Koka, an algal bloom in Lake Aba Samuel, industrial pollution of the Akaki River and nitrate pollution of the Awash River (Mosello *et al.* 2015).

Salinization
Salinity problems due to waterlogging were observed in irrigated lands along the Awash River. In the 1980s, thousands of hectares of the Amibara plantation for cotton, in the middle Awash basin, had to be abandoned after less than five years of irrigation farming due to faulty drains (Environmental Resources Management Ltd 2007).

Prospects for agricultural water management
Recurring droughts and growing population pressure drove the Ethiopian government to prioritize irrigated agriculture in the country's development agenda in order to reduce the food deficit. Targets of the 2006-2010 PASDEP, 487,000 ha of small-scale irrigation and 323,000 ha of medium- and large-scale irrigation by the end of the period (PASDEP), were mostly achieved. Ethiopia's first Growth and Transformation Plan (GTP) targeted a colossal increase in irrigated land area for the period 2010-2015, for a total of 1.85 million ha in small-scale irrigation and an additional 785 583 ha in medium- and large-scale irrigation schemes by 2015 (GTP 2010). These were almost reached but mostly through traditional water management, often with temporary structures and not full-control irrigation schemes.

The second GTP once more set a vast increase for the period 2015-2020, although this small-scale irrigation target is lower than in the 2010-2015 GTP, with 1.7 million ha under small irrigation schemes and 954,000 ha under medium and large scale by 2019/2020 to develop 98 per cent of the irrigation potential (GTP2). The area under irrigation is mostly expanded with small irrigation schemes, requiring lower capital and technology investments and reaching small communities.

However, despite the immense increases mentioned above, the harvested irrigated crops were in 2014/2015 not yet using this new potential fully. In addition, the rapid infrastructure development should be quickly followed by institutional development and in particular creation of water use associations for local irrigation management to ensure these new irrigation schemes are properly managed, operated and maintained.

BIOGAS

Biogas technology has environmental benefits, since the technology provides an opportunity to treat and re-utilize a variety of organic wastes and thereby reduce environmental problems. For instance, pathogenic organisms are removed in the process of anaerobic digestion taking place in the biogas digester. However, nitrogen, phosphorous and other minerals remain largely unchanged; therefore, effluent from a digester must be retained in a holding pond and used either as recycled flush water or for irrigation (Engler *et al.* 1999). However, in the Ethiopian context, there is no empirical data that characterizes quantitatively the composition of the bioslurry from different households that own biogas digesters.

In this regard, a household survey of 71 households who installed biogas digesters in the Oromia (21), SNNPR (22), Amhara (13) and Tigray (15) regions revealed two relevant information; (1) 91.6 per cent used bioslurry as fertilizer, and (2) utilization of bioslurry as fertilizer varied from region to region. In urban areas such as Butajira and Bishoftu towns, bioslurry was mostly discarded to wastelands instead of using it as organic fertilizer. This shows that there is also a mismanagement issue regarding bioslurry utilization. However, water pollution issues associated with mismanagement of the bioslurry have not been documented.

Bioslurry has known additional benefits such as a basal manure and as a foliar application or spray, an insect repellent, increasing soil fertility and improving the soil structure and water holding capacity, decreasing soil erosion, concentrated feed for cattle, pigs, and fish, and production of earthworms and algae, for the production of vitamin B12 and amino acids for animal growth, increasing quality and quantity of organic grown flowers and vegetables, increase the availability of nutrients for soil micro-flora like nitrogen-fixing and phosphor solubilizing organisms, reducing the use of phosphate, a non-renewable source that is being depleted globally, reducing wastewater, water pollution, greenhouse gas emissions and noxious odours, and reducing weed growth and diminishing attractiveness to insects or flies (Warnars and Oppenoorth 2014). Consequently, it can only be speculated that nitrogen and phosphorous from bioslurry, possibly applied to household farms and wastelands, may be washed away and ultimately lead to nonpoint source pollution of nearby water bodies.

4.6.6 Main conclusions and recommendations

Synthesis of the findings

Water in Ethiopia is mostly polluted in urban and industrial areas, but in rural areas mainly soil salinization linked to irrigation was observed. Due to the direct discharge of industry waste into rivers, most of the rivers around Addis Ababa and industrial cities are polluted. Influent from agricultural land to water bodies is also a source of pollutants.

There is a general claim that the use of bioslurry as fertilizer causes less pollution compared to the use of inorganic fertilizers such as urea and diammonium phosphate, which are commonly used in

Ethiopia. Such an advantage can be utilized to promote the use of biogas technology in developing countries such as Ethiopia. However, there is a lack of empirical data on whether the users are implementing good waste management practices not to pollute local water bodies due to the adoption of biogas technology. In particular, information on the bioslurry/digestate management is missing to reach a strong conclusion.

Practices and policies to improve sustainability

It is well known that the currently dominant practice, especially in rural households of Ethiopia, is the unsustainable use of wood and charcoal to satisfy energy needs. If this practice continues, it will further accelerate the deforestation rate in the country. If this trend is to be reversed, it is critical to diversify energy sources. Biogas is an attractive option in this regard. Moreover, biogas complies with the principles of the country's Energy Policy and Environmental Protection strategy as stipulated in the National Biogas Programme. It is thus recommended that farmers' awareness and technical skill is enhanced by informing them of the benefits of bioslurry – i.e., that it is more environmentally friendly since it causes less pollution to water bodies, cost-effective because it is locally available, increases crop yields equivalent to or even better than chemical fertilizers, contributes to waste minimization, etc.

Future monitoring

Due to a lack of data, we cannot be sure if water bodies are directly receiving biogas effluents in the country. Therefore, researchers in the country should fill this gap by characterizing the composition of bioslurry from anaerobic digestion and conducting water quality assessment of water bodies receiving these effluents directly, if any.

4.6.7 References

Awulachew, S.B., Erkossa, T. and Namara, R. (2010). *Irrigation Potential in Ethiopia – Constraints, and Opportunities for Enhancing the System.* International Water Management Institute. https://ethiopianagriculture.files.wordpress.com/2010/11/ethiopia-irrigation-diagnostic-july-20101.pdf.

Engler, C.R., Jordan, E.R., McFarland, M.J. and Lacewell, R.D. (1999). Economics and environmental impact of biogas production as a manure management strategy. In: *Proceedings of the 1999 Texas Animal Manure Management Conference*. Texas A&M University. College Station, TX, USA. 109-114.

Ethiopia Environmental Protection Authority (2003). *State of Environment Report of Ethiopia*. Addis Ababa.

Ethiopia Environmental Protection Authority (2008). *Ethiopia Environment Outlook: Environment for Development*. Addis Ababa.

Ethiopia Environmental Protection Authority (2012). *United Nations Conference on Sustainable Development (Rio+20): National Report of Ethiopia.* Addis Ababa.

Environmental Resources Management Ltd (2007). *Ethiopia – Irrigation and Drainage Project: Environmental and Social Management Framework.* World Bank. Washington, D.C. http://documents.worldbank.org/curated/en/156341468031586770/Environmental-and-social-management-framework.

Ministry of Finance and Development (2010). *Growth and Transformation Plan 2009/10-2014/15.* Addis Ababa.

Mosello, B., Calow, R., Tucker, J., Parker, H. Alamirew, T. Kebede, S. *et al.* (2015). *Building Adaptive Water Resources Management in Ethiopia*. Overseas Development Institute. London.

Waarnars, L. and Oppenoorth, H. (2014). *Bioslurry: A Supreme Fertilizer. A Study on Bioslurry Results and Ises*. K. Atkinson, (ed.). Hivos People Unlimited. Delta Hague.

4.7 Indicator 7. Biological diversity in the landscape

4.7.1 Researcher(s)

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4.7.2 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.

4.7.3 Measurement unit(s)

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

4.7.4 Overall methodology of the implementation

GIS techniques are useful to evaluate the spatial distribution of the biodiversity hotspot areas and bioenergy production areas. Secondary data (literatures, reports, survey results, national figures, etc.) on forest cover, spatial distribution of biodiversity hotspot areas and firewood specifically have been used.

4.7.5 Key findings

NATIONAL LEVEL

Vegetation types of Ethiopia are being considered as ecosystems where the classification is as follows: Afroalpine and Sub-Afroalpine, Dry Evergreen Montane Forest and Grassland Complex, Moist Evergreen Montane Forest, *Acacia Commiphora* Woodland, *Combretum-Terminalia* Woodland, Lowland Semi-evergreen Forest, Desert and Semi- Desert Scrubland, and Inland Waters (Sebsebe *et al*. 1996; Environmental Protection Authority [EPA] 1997; Zerihun 1999).

Ethiopia is a biodiversity hotspot country, ranking 5th in the region and 25th in the world in biodiversity. Ethiopia hosts two of the 34 global mega-biodiversity hotspots, namely the Eastern Afromontane and the Horn of Africa hotspots (Friis *et al.* 2010). Ethiopia is also one of the nine vavilove agro-biodiversity centres of the world. The flora and fauna of Ethiopia includes between 6,500 and 7,000 plant species, 240 mammals, and 845 bird species, of which 1,150 plant species, 22 mammals, and 24 bird species are endemic to the country (Bongers and Tennigkeit 2010).

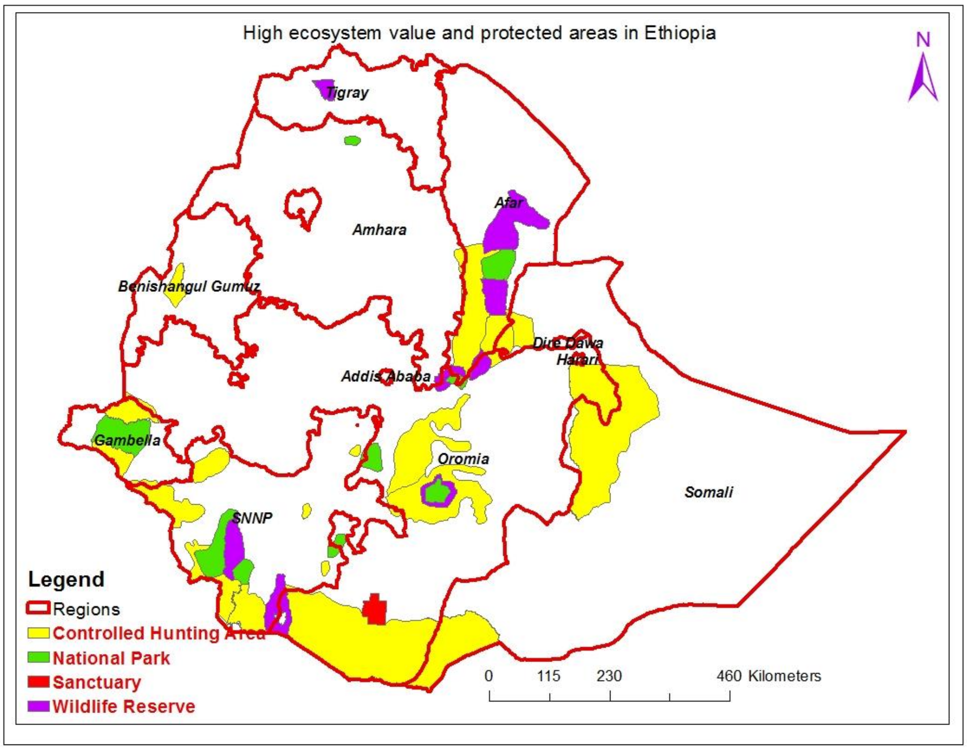
Biodiversity hotspots and protected areas share a total surface area of 30,361 km^2 (2.69 per cent) of the total area of the country, which is 1,127,127 km^2.

Owing to its huge biodiversity Ethiopia has demarcated different biodiversity hotspot areas, which are categorized as national parks, controlled hunting areas, sanctuaries and wildlife reserves. These biodiversity-rich areas are distributed in different ecosystems and are known for their unique compositions of plants and animals (Map 4.7; Table 4.19). Biodiversity hotspots and protected areas share a total surface area of 30,361 km^2 (2.69 per cent) of the total area of country, which is 1,127,127 km^2.

In spite of the difficulties in providing a concrete estimate, the size of the landmass that has global and national significance, due to its high biodiversity value not limited to instituted protected areas, is much larger than the nationally recognized protected areas. Despite the rich biodiversity, there are many species with rapidly declining populations and at risk of extinction unless they are protected. Indigenous timber species such as *Junipers procera*, *Cordia africana*, *Podocarpus falcatus* and *Olea africana* are some of the plant species that are gazetted to be protected in the country.

Despite the diverse ecosystems with a huge wealth of plants, animals, and microbial species, in Ethiopia inadequate attention has given to the conservation and sustainable use of these resources. Not all of the areas with global and national significance are comprehensively protected, for instance, only Awash and Semen Mountains National Parks are demarcated and gazetted so far. Most Protected Areas may have guards but lack clear demarcation of boundaries and hence are exposed to continued encroachment. In addition, other major factors contributing to accelerated decline of the country's biological resources include fast population growth, weak institutional capacity to implement policies, poverty and high dependence on natural resources, poor market performance and climate change.

Map 4.7. Protected areas in Ethiopia



Source: Lakew Berhanu, Ethiopia's Protected Area System Plan Project, Wildlife Conservation Department, Ministry of Agriculture

Table 4.19. Ecosystem hotspot areas in Ethiopia

Name	Area (km²)	Ecosystem category
Abijata-Shalla Lakes National Park	887	*Acacia-Commiphora* woodland
Awash National Park	756	*Acacia-Commiphora* woodland and evergreen scrub
Bale Mountains National Park	2 471	Afroalpine and sub-afroalpine, dry evergreen montane forest and evergreen scrub
Gambella National Park	5 061	Lowland (semi) evergreen forest, *Combretum-Terminalia* woodland and savanna and moist evergreen montane forest
Mago National Park	2 162	Desert and semi-desert scrubland, *Acacia-Commiphora* woodland and *Combretum -Terminalia* woodland and savanna
Nechisar National Park	514	*Acacia-Commiphora* woodland and evergreen scrub
Omo National Park	4 068	Desert and semi-desert scrubland, *Acacia-Commiphora* woodland and *Combretum-Terminalia* woodland and savanna
Simien Mountains National Park	179	Afroalpine and sub-afroalpine and dry evergreen montane forest
Yangudi-Rassa National Park	4 731	Desert and semi-desert scrubland and *Acacia-Commiphora* woodland
Babille Elephant Sanctuary	6 982	Desert and semi-desert scrubland, *Acacia-Commiphora* woodland and evergreen scrub
Senkelle Swayne's Hartebeest Sanctuary	54	*Acacia-Commiphora* woodland and evergreen scrub
Yabello Sanctuary	2 496	Desert and semi-desert scrubland and evergreen scrub
Total	30 361 km²	

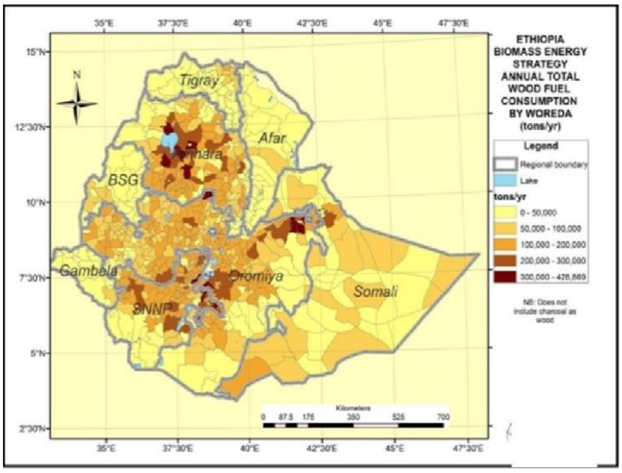
Source: Mohammed Abdi *et al.* 2003.

FIREWOOD

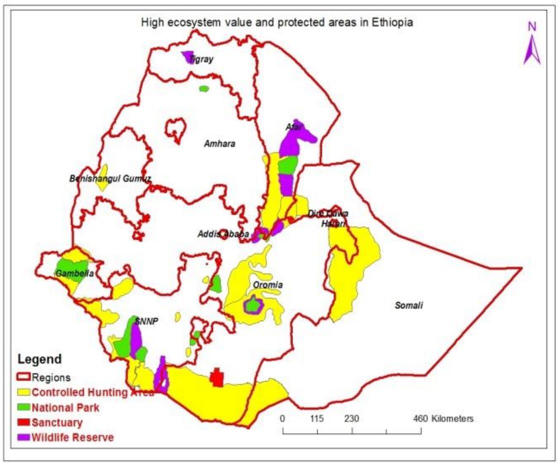
In Ethiopia, wood fuel is the major energy sources, accounting for an estimated more than 90 per cent of annual consumption. Despite few variations, wood biomass is used as a source of energy across all regions and in cities and urban areas. As mentioned earlier and also in Table 4.19, national parks, sanctuaries, wildlife reserve and controlled hunting areas constitute a unique biodiversity in the country. Despite the comparatively large area coverage of biodiversity hotspots in Ethiopia, an estimated 105,172,465 tons of wood fuel is produced and consumed annually, which mainly comes from these nationally recognized high value ecosystems.

In Ethiopia, the heavy reliance on biomass energy of a large majority of the population has been putting severe pressure on the sustainable management of these biodiversity hotspots. For instance, a large volume of wood fuel use occurs around and to the east of Lake Tana in Amhara region, which is a biodiversity hotspot (Map 4.8). There is also high consumption of wood fuel along the Hareghe highlands, areas that host one of the 34 global biodiversity hotspots, and on either side of the Rift Valley in the SNNPR and Oromia regions (Map 4.9). More specifically, controlled hunting areas in Ethiopia are most vulnerable to woodfuel collection, of up to 300,000 tons per year. National parks are also one of the areas where a large volume of wood fuel is produced in the country, implying how exposed these sites are to severe deforestation due to fuelwood collection and use (Table 4.20).

Map 4.8. Fuel wood consumption by woreda



Map 4.9. Hotspot ecosystem areas



Source: Geissler *et al.* 2013.

Table 4.20. Spatial distribution of fuelwood consumption areas in and the surrounding hotspot ecosystem areas

Hotspot area name	Wood fuel consumption tons/year				
	0 – 50 000	50 000 – 100 000	100 000 – 200 000	200 000 – 300 000	300 000 – 400 000
Controlled hunting area					-
National park	-				-
Sanctuary	-		-	-	-
Wildlife reserve			-	-	-

Grey areas show the range of charcoal for different ecosystem hotspot areas.

Based on the spatial distribution of biodiversity hotspot areas, wood fuel consumption in and around controlled hunting areas ranges from 0 to 300,000 tons/year. In and around national parks and in sanctuary areas and wildlife reserves, the magnitude of wood fuel consumption ranges from 50,000 to 100,000 and from 0 to 100,000 tons/year respectively.

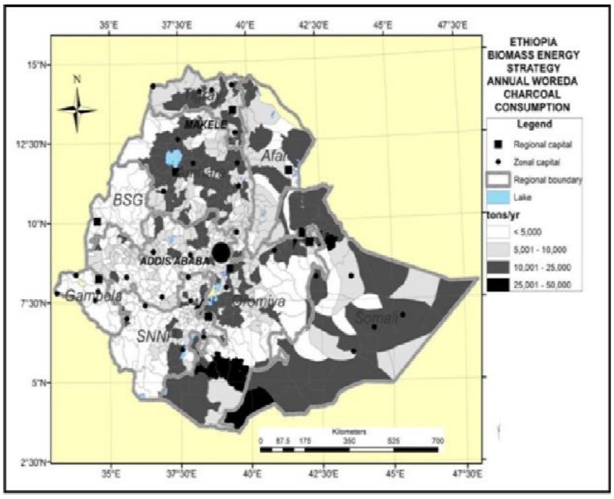
CHARCOAL

Charcoal production

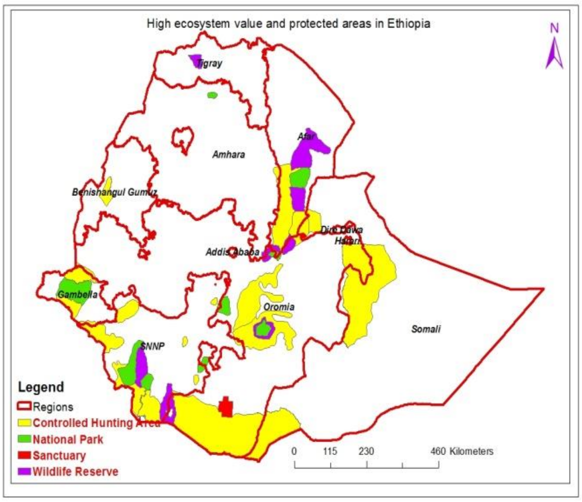
Charcoal is another major energy source in Ethiopia, and its production and consumption is increasing. Most case studies reveal that charcoal production in Ethiopia is unsustainable; in some areas such as the central Rift Valley, it has already resulted in rapid land-use transformation and poor natural regeneration of native plant species, exposing the area to desertification risks. Charcoal production and use vary from place to place. For instance, the Afar and Somali regions are among the major charcoal-consuming areas in the lowlands. In highlands, eastern Oromiya, Amhara and Tigray regions use a considerable amount of charcoal.

In Ethiopia, charcoal production is estimated at 5,713,700 tons/year (Table 4.21). Unfortunately, the overlay of different maps (Map 4.10 and Map 4.11) shows that most charcoal production and consumption is around major nationally recognized high biodiversity value areas, implying the harm that charcoal production could cause to these ecosystems unless it is urgently monitored and managed. For instance, unsustainable charcoal production is carried out throughout all hunting areas with a production rate of 50,000 tons per annum. Charcoal is also produced and used in and around national parks and wildlife reserves.

Map 4.10. Charcoal consumption by woreda



Map 4.11. Hotspot ecosystem areas



Source: Geissler *et al.* 2013.

Table 4.21. Spatial distribution of charcoal consumption areas in and the surrounding hotspot ecosystem areas

Hotspot area name	**Charcoal consumption tons/year**			
	0 – 5 000	5 001– 10 000	10 001 – 25 000	25 001 – 50 000
Control hunting area				
National park	-			
Sanctuary	-	-	-	
Wildlife reserve			-	-

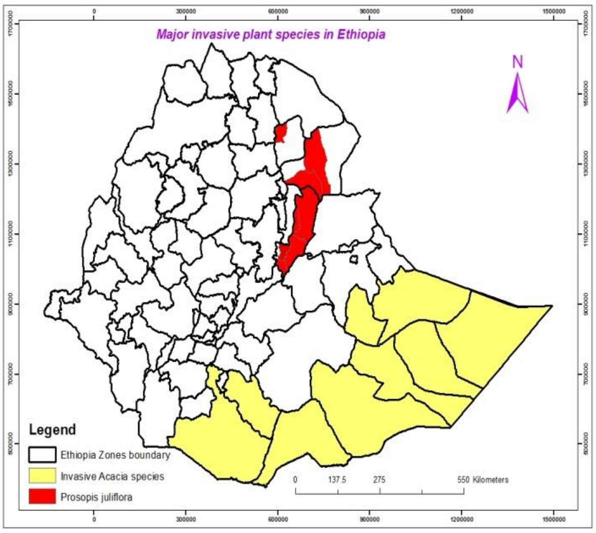
Grey areas show the range of the amount of charcoal for different ecosystem high spot areas

Based on the spatial distribution of biodiversity hotspot areas, charcoal consumption in and around controlled hunting areas ranges from 0 to 50,000 tons/year. In and around national parks and sanctuary areas, charcoal consumption ranges from 5,001 to 25,000 and from 25,001 to 50,000 tons/year respectively. In and around wildlife reserve areas, charcoal consumption ranges from 0 to 10,000 tons/year.

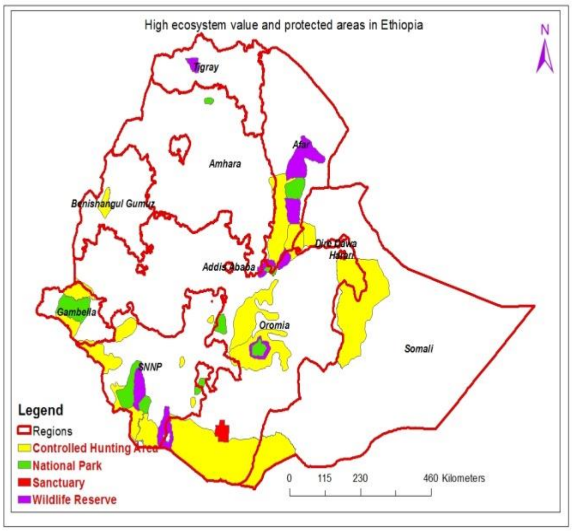
Invasive species distribution

In Ethiopia so far, 37 invasive alien species and several native bush encroachers are identified. The most important invasive species that are having severe impacts on ecosystem productivity and biodiversity conservation and hence need to be controlled and eradicated include *Parthenium hysterophorus*, *Eichhornia crassipes*, *Prosopis juliflora* and *Lantana camara* (Taye *et al.* 2007). The major native bush encroachers include *Acacia drepanolobium, A. melifera* and many others.

Map 4.12. Invasive species distribution



Map 4.13. Hotspot ecosystem areas



Source: Pastoral Agriculture Rural Development Bureau [PARDB] 2008.

According to Maps 4.12 and 4.13, the spatial distribution of high-ecosystem-value areas and invasive specious were found to be overlapping, with rapid expansion of invasive species to high value areas over time. *Prosopis juliflora*, for instance, has been invading protected areas in the Afar region, displacing several indigenous plant and animal species. So far *Prosopis* has covered over 1 million ha of land in the Afar region alone (Figure 4.16). In the southern and southeastern lowlands where there are wildlife reserves, native acacias are aggressively encroaching and causing damage to the ecosystems.

In the Afar region, charcoal production and pod crushing were introduced as control means in areas where *Prosopis* was established well and had mature trees. To pilot the interventions, four cooperatives were established in Gewane and Amibara districts and were granted official licences by the government to implement the identified activities. Cooperative members were trained and technically supported on how to manage their interventions, which included: *Prosopis* tree harvesting techniques to prevent coppicing; utilization of time and labour for efficient charcoal production using metal kilns; pod collection, drying, and crushing using small hammer. A market survey was also carried out to better understand and connect the charcoal trade to cities including Nazareth and Addis Ababa.

Unfortunately, these and many other invasive species management efforts such as those on *Parthenium* and water hyacinth did not bring sustainable change in managing them; rather, most invasive species are encroaching biodiversity hotspot areas in many parts of the country. The major reasons for the lack of success include weak participation of the local administration and communities in the process, lack of or weak monitoring and evaluation of interventions, lack of policies and overall poor institutional follow-up of interventions. Scarcity of knowledge on technologies and about the dynamic invasion strategy of the species are also undermining success.

Figure 4.16. Metal kiln

Source: Taye *et al*. 2007.

4.7.6 Conclusions and recommendations

Synthesis of the findings

Ethiopia is a biodiversity hotspot country, ranking 5th in the region and 25th in the world in biodiversity. Ethiopia hosts two of the 34 global mega-biodiversity hotspots. When we consider areas of high biodiversity value in the most comprehensive terms, and not limited to instituted protected areas, the size of the country's landmass that has global and national significance is much larger than the nationally recognized protected areas. However, most of these areas are under persistent threats. A major threat is the collection and consumption of biomass energy.

Preliminary assessments show that the areas under plantation to be used as a source of wood fuel and charcoal overlap with high conservation value areas, constituting an estimated 30,361 km^2 or 0.2 per cent of the total landmass of the country. This alone shows the already huge land-use competition between conservation and biomass-based energy production, which is expected to grow dramatically in the near future with rapidly increasing population. Similarly, the expansion of invasive species, which on the other hand are becoming sources of charcoal, is increasing. More-efficient stoves, biogas, cattle dung and crop residue are important avenues to replace the use of charcoal and fuel wood and thereby minimize the pressure on biodiversity hotspot areas.

Practices and policies to improve sustainability

The following recommendations are proposed:

- Plan and implement appropriate strategies and technologies that will enhance the use of solid biomass (wood fuel and charcoal) to minimize pressure on biodiversity hotspots.
- Promote effective and efficient utilization of biogas, cattle dung and crop residue-based energy production and energy utilization.
- Establish a continued biodiversity hotspot areas monitoring system and prepare up-to-date and accurate vulnerability trends that advise risk management.
- Design and implement effective, efficient and integrated use of invasive species as sources of value-added energy to minimize their effect on biodiversity hotspots.
- Disseminate more efficient bioenergy technologies, improve policies and research findings in order to add value to the energy sector and to minimize its effect on sustainable biodiversity management.

Monitoring
Ethiopia needs to plan and implement a strategy that effectively and efficiently uses alternative energy sources such as wood fuel and biogas. This, however, requires putting in place an appropriate monitoring strategy, which again requires detailed information. Without the necessary data on demand and supply chains and on the production-to-consumption actors, it will be difficult to plan and implement an effective monitoring system, and emphasis should be placed on accessing data and on overall knowledge management in the bioenergy sector.

4.7.7 References

Ethiopia Environmental Protection Authority (1997). *National Conservation Strategy Ethiopia*. Addis Ababa.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Mohammed, A., Yirmed, D., Mengistu, W., Bekele, J., Almaz, B. and Azam, Y. (2003). *Terrestrial Wild Animals and Protected Areas of Ethiopia.* Prepared for Biodiversity Strategy and Action Plan Project. Ethiopia.

Pastoral Agriculture Rural Development Bureau (2008). Ethiopia.

Sebsebe, D., Mengistu, W. and Yilma, D. (1996). *Ethiopia's Natural Resource Base in Important Bird Areas of Ethiopia: A First Inventory*. Ethiopian Wildlife and Natural History Society. Addis Ababa.

Taye, T., Fessehaie, R. and Firehun, Y. (2007). *Invasive Alien Weed Species in Ethiopia: Biology, Distribution and Importance, and Available Control Measures.* Addis Ababa.

Zerihun, W. (1999). Forests in the vegetation types of Ethiopia and their status in the geographical context. In: S. Edwards, Abebe Demissie, Taye Bekele and G. Haase (eds.). *Forest Genetic Resource Conservation: Principles, Strategies and Actions.* Addis Ababa, June 21-22.

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

4.8.1 Researcher(s)

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4.8.2 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 (amongst 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

4.8.3 Measurement unit (s)

(8.1) and (8.2) Hectares and percentages
(8.3) Percentages
(8.4) Hectares per year

4.8.4 Overall methodology of the implementation

The total land area in a country used for bioenergy production is derived from spatial data or estimated from data on land used for solid biomass production based on the FAO definition of forest lands. For this purpose, raw land cover satellite data produced by the Catholic University of Louvain-Geomatics and the European Spatial Agency, ESA, deliver consistent global LC maps at 300 m spatial resolution on an annual basis from 1992 to 2015. The CRS used for the global LC databases is a geographic coordinate system (GCS) based on the WGS84 reference ellipsoid. The LC-CCI maps include 22 classes at level 1, i.e., global scale, and 14 additional level 2 classes at a regional scale, to allow a more detailed description of LC.

4.8.5 Key findings

Land use and land cover (LULC) status of Ethiopia
In Ethiopia, forest is defined as land occupied with trees (natural and planted, including bamboo) attaining a height of more than 2 metres at maturity, canopy cover of more than 20 per cent and covering an area of more than 0.5 ha, with a minimum width of 20 metres or not more than two-thirds of its length (Ministry of Environment, Forest and Climate Change [MEFCC] 2017; MEFCC 2018a). Accordingly, the forest coverage of Ethiopia is estimated to be around 17.35 million hectares or 15.5 per cent of the land mass of the country (MEFCC 2016; MEFCC 2017; MEFCC 2018a)[2].

Detailed land cover types of Ethiopia, as well as shares and changes between 2000 and 2015, are provided in Table 4.22, Map 4.14 and Figure 4.15. Of the 11 LULC types identified and evaluated in the country, broad-leaved deciduous, broad-leaved evergreen, crop land, irrigated or post flooding, and grassland showed growth over the 15-year of period, while the rest declined in their cover (Table 4.22). Between 2000 and 2015, large areas of bare lands, rain-fed crop land, and herbaceous cover were converted to other LULC types, while most bare lands and shrublands lost substantial area within a 15-year period across the country (Table 4.22).

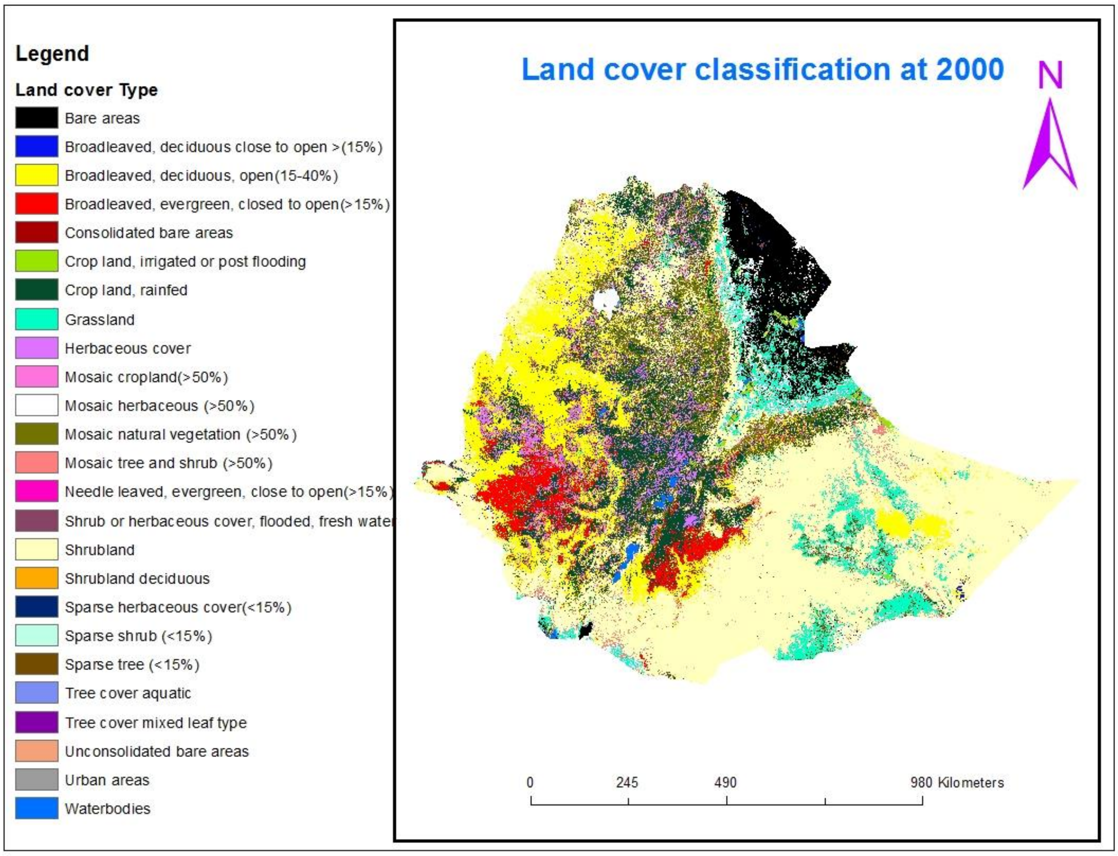
[2] This forest definition differs from the Food and Agriculture Organization (FAO) forest definition and therefore from the definition used in the data reported to the Global Forest Resources Assessment of the FAO. More details on the differences are included in Indicator 3.

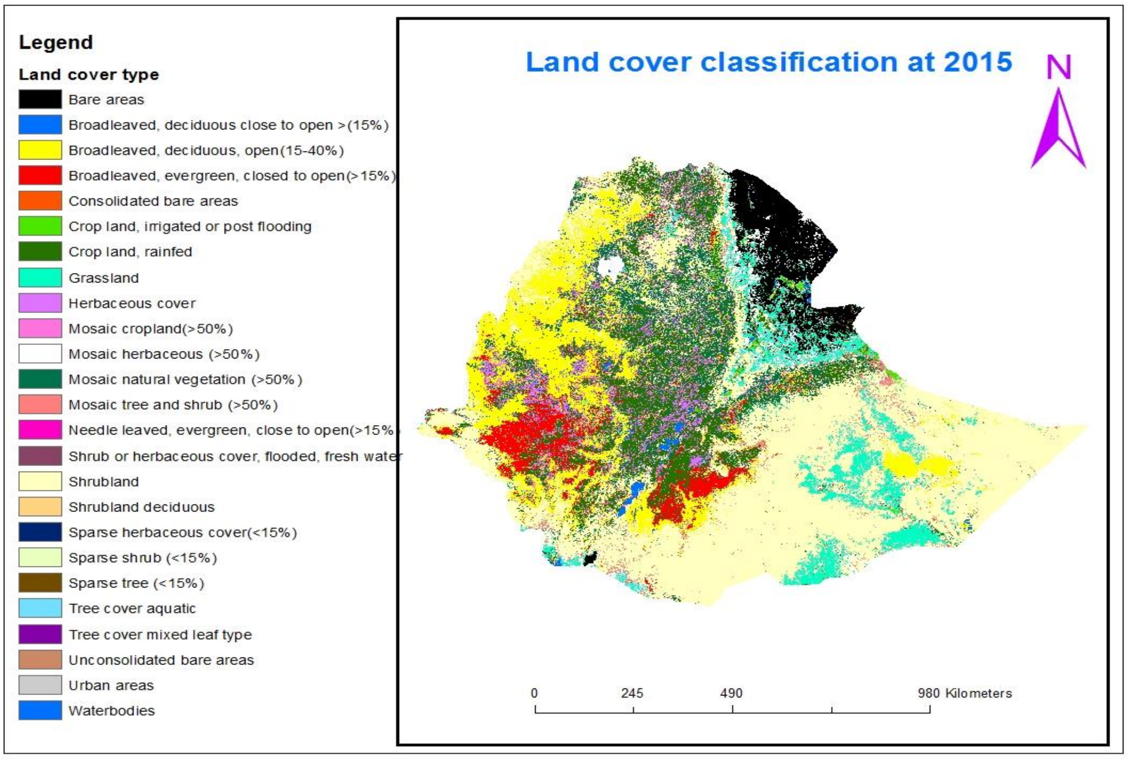
Table 4.22. Land-cover types of Ethiopia, shares and changes between 2000 and 2015

	2000		2015		2000-2015
LULC _Class	Area_ (ha)	%	Area_ (ha)	%	Land use change
Bare areas	6 754 312	5.98	6 657 220	5.90	-97 093
Broadleaved, deciduous close to open > (15%)	336 705	0.30	594 299	0.53	257 594
Broadleaved, deciduous, open (15-40%)	15 030 298	13.31	15 576 330	13.80	546 033
Broadleaved, evergreen, closed to open (>15%)	4 309 569	3.82	4 516 064	4.00	206 495
Consolidated bare areas	554 059	0.49	553 892	0.49	-167
Crop land, irrigated or post flooding	565 172	0.50	589 483	0.52	24 312
Crop land, rainfed	12 497 771	11.07	12 458 452	11.03	-39 319
Grassland	6 421 948	5.69	6 946 473	6.15	524 525
Herbaceous cover	2 015 270	1.78	2 004 399	1.78	-10 871
Mosaic cropland (>50%)	4 910 059	4.35	4 829 948	4.28	-80 111
Mosaic herbaceous (>50%)	1 562 348	1.38	1 536 079	1.36	-26 269
Mosaic natural vegetation (>50%)	7 909 943	7.01	7 461 619	6.61	-448 324
Mosaic tree and shrub (>50%)	1 711 077	1.52	1 813 790	1.61	102 713
Needle leaved, evergreen, close to open (>15%)	19 881	0.02	437	0.00	-19 444
Shrub or herbaceous cover, flooded, fresh water	165 292	0.15	164 280	0.15	-1 012
Shrub land	46 572 602	41.25	46 084 225	40.82	-488 378
Shrub land deciduous	259 014	0.23	258 651	0.23	-363
Sparse herbaceous cover (<15%)	7 373	0.01	6 633	0.01	-740
Sparse shrub (<15%)	41 205	0.04	38 075	0.03	-3 130
Sparse tree (<15%)	666 589	0.59	192 851	0.17	-473 738
Tree cover aquatic	81 570	0.07	81 782	0.07	212
Tree cover mixed leaf type	9 093	0.01	32	0.00	-9 061
Unconsolidated bare areas	95	0.00	95	0.00	1
Urban areas	39 116	0.03	86 336	0.08	47 220
Water bodies	469 086	0.42	458 003	0.41	-11 083
Total area	112 909 449	100.00	112 909 449	100.00	0

Source: Raw land use data used from raw land use data used from Catholic University of Louvain-Geomatics and ESA

Map 4.14. Land cover change of Ethiopia between 2000 and 2015



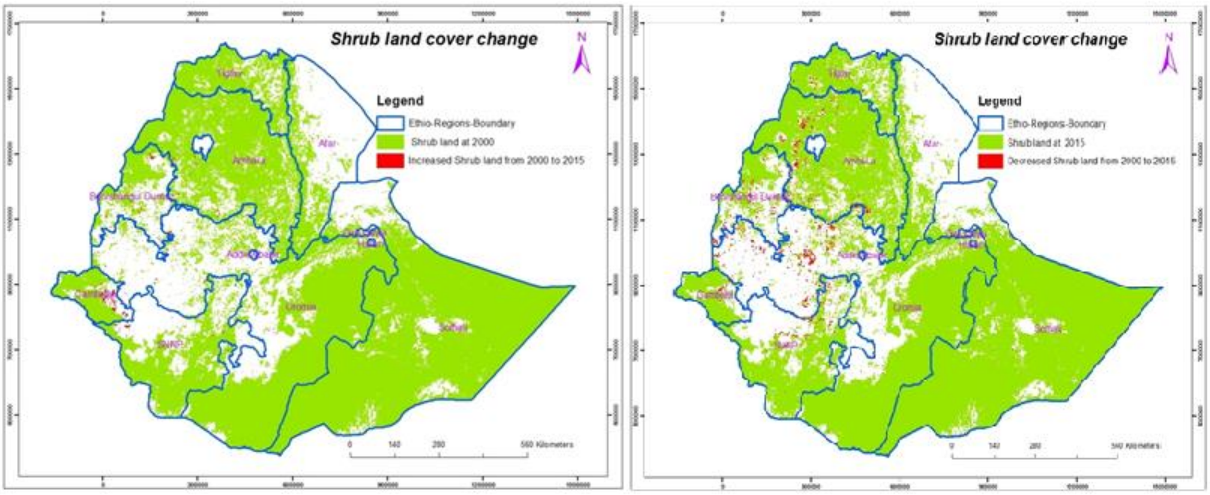


Source: Raw land use data used from Catholic University of Louvain-Geomatics and ESA.

Forest loss (>10 per cent canopy cover) for the period 2001-2014 was 381,285 ha (MEFCC 2018) (Table 4.23). Deforestation and land degradation are widespread in Ethiopia due to the high levels of human pressure and unsustainable land use. Given the country's largely rugged topography, an estimated 27 million ha of land in the highlands is degraded, of which 14 million ha is severely eroded (Lemenihand Kassa 2014; Berry 2003 cited in MEFCC 2018). At the national level, the rate of deforestation and forest degradation ranges from 140,000 to 200,000 ha/year and has resulted in severe land degradation and loss of biodiversity (FAO 2010 cited in MEFCC 2018). There has been a continued loss of forest between 2000 and 2010.

FAO (2015) estimated a decline of forest cover from 15.11 million ha in 1990 to 12.5 million ha in 2015. In other words, Ethiopia lost over 2.6 million ha of her forests, with an annual average loss of 104,900 ha between 1990 and 2015 (FAO 2015) (Table 4.23). The losses were even worse until 2010 (141000 ha lost per year since 1990), slightly compensated by an annual increase of 40,600 ha between 2010 and 2015.

Map 4.15. Shrub land cover change of Ethiopia between 2000 and 2015



Source: Raw land use data used from Catholic University of Louvain-Geomatics and ESA

Table 4.23. Tree cover loss and gain

Regional state	Forest loss (ha) (>10% canopy cover)	Forest gain (ha) (>50% canopy cover)	Regional state	Forest loss (ha) (>10% canopy cover)	Forest gain (ha) (>50% canopy cover)
Period	**2001-2014**	**2001-2012**	**Period**	**2001-2014**	**2001-2012**
Addis Ababa	335	579	Harari People	16	0
Afar	72	12	Oromia	188 960	42 351
Amhara	7 385	4 264	Somali	869	251
Benshangul-Gumaz	58 755	922	SNNPR	107 406	12 609
Dire Dawa	3	0	Tigray	1 569	389
Gambella Peoples	15 914	1 161	**Total**	**381 285**	**62 538**

Note: Due to variation in research methodology and/or date of content, tree cover and tree cover loss and gain statistics cannot be compared against each other. Accordingly, "net" loss cannot be calculated by subtracting tree cover gain from tree cover loss, and current (or post-2000) tree cover cannot be determined by subtracting annual tree cover loss from tree cover in 2000. Further, "tree cover" does not equate to "forest cover." "Tree cover" refers to the biophysical presence of trees, which may be a part of natural forests or tree plantations. Thus, loss of tree cover may occur for many reasons, including deforestation, fire, and logging within the course of sustainable forestry operations. Similarly, tree cover gain may indicate the growth of tree canopy within natural or managed forests.
Source: MEFCC 2018.

The causes of land use and loss of forest area

The drivers of deforestation and forest and land degradation vary greatly at the regional and local levels. The main direct drivers of deforestation are small-scale agricultural expansion and fuelwood consumption, and to a lesser extent illegal logging and forest fires (FDRE 2011 cited in MEFCC 2018). Another important driver has been identified as large-scale agricultural investments, which until recently were promoted by the government as a vehicle for rural development and economic growth. Overgrazing, settlement, and uncontrolled tree harvesting and utilization also contribute. On public land (which is typically where forests are found), there may be no sense of ownership of the resource, leading to a tragedy of the commons problem where optimization of individual harvest levels leads to degradation of the common resource.

Fire is also responsible for the loss of forest in the country, affecting the distribution, and composition of forest resources (Lemenih and Bekele 2008; Wassie, Teketay and Powell 2005). For instance, the most devastating wave of forest fires, which occurred in 2000 due to an extended drought, damaged over 150,000 ha of forested lands throughout the country (Teketay 2001). This trend is more pronounced in the high forest areas compared to other ecosystems and has a direct implication on the change of these forest ecosystems (Lemenih and Bekele 2008).

Plantation status of Ethiopia

Plantation forests in Ethiopia are mainly dominated by *Eucalyptus*, *Cupressus*, *Pinus* and *Acacia* genera (Bekele 2011; Moges, Eshetu and Nune 2010). Among these, *Eucalyptus* species hold the largest share and cover about 56 per cent of the total plantation by area (Bekele 2011). Eucalyptus is preferred owing to its fast-growth nature, coppicing ability and wider adaptation to different ecological conditions (FAO 2009). It also serves as the main source of firewood, farm implements, poles and posts in Ethiopia (Kelemu and Tadesse 2010).

The major regional states that account for the majority of the total plantation forest area are Oromia, Amhara, SNNPR and Tigray. These are also the regions with major commercial forest plantations (Table 4.24). Plantation forests managed for the production of sawn wood dominate and cover more than 50 per cent of the total area, and the residues are used for firewood and local construction materials (Table 4.25).

Table 4.24. Industrial plantation forest areas in ha by species and region in Ethiopia

Regional state	Eucalypts	Cypress	Juniper	Pines	Grevillea	Others	Total area
Oromia	29 700	32 100	4 400	3 500	1 300	7 800	78 800
Amhara	18 000	23 400	300	100	-	2 800	44 600
SNNPR	20 300	7 000	-	-	-	-	27 300
Tigray	39 700	-	-	-	-	-	39 700

Source: Data collected from regional bureaus of agriculture.

Table 4.25. Non-industrial plantations forest areas including firewood and charcoal by region in Ethiopia

Regional state	Area of non-industrial plantations/woodlots (ha)	Area of peri-urban plantations (ha)
Oromia	27 800	26 700
Amhara	639 400	-
Southern	64 000	-
Tigray	23 700	-
Total	754 900	26 700

Source: FAO 2015.

Table 4.26. Forest and woodland status at 2015

Forest area 2015		Other woodland 2015	
Area in 1 000 ha	% of land	Area in 1 000 ha	% of land
12 499	11.4	40 631	37.1

Source: FAO 2015.

Contribution of animal feed

According to CSA (2000; 2015) animal feeds are classified as green fodder (grazing), crop residue, improved feed, hay, industrial by-products and other feeds. Green fodder is simply pasture grasses; crop residue includes harvested by-products (straw and chaff of cereals and pulses, etc.); improved feed includes alfalfa; hay includes any type of grass, clover etc. cut and dried as fodder; and finally industrial by-products include oil cake (rapeseed cake, nueg cake, sunflower cake, etc.), bran, and brewery residue.

Green fodder (grazing) remains the major type of feed, and its share increased greatly between 2000 and 2015 (Table 4.27) due to the conversion of shrubland and woodland to grass land. It is followed by crop residue, which has declined slightly. Hay and by-products have also decreased (Table 4.27). A very small amount of improved feed was used and has not really changed.

There is a strong relationship between land cover change and change in animal feed holders (Table 4.28, Figures 4.17 and 4.18). Grassland increased by 524,525 ha from 2000 to 2015, and grass fodder also increased by 4,489,214 holders. Crop residue increased by 4,147,865, which was mainly generated from irrigated crop land rather than from rain-fed crop land.

Table 4.27. Change of animal feed holders

Item	2000		2015		Change number of holders (2000-2015)
	Number of holders reporting	Percentage from the total feed	Number of holders reporting	Percentage from the total feed	
Green fodder/ Grazing	9 789 364	40.3%	14 278 578	56.2%	4 489 214
Crop residue	8 128 882	33.5%	12 276 747	30.1%	4 147 865
Improved feed	37 296	0.2%	309 030	0.3%	271 734
Hay	2 874 880	11.8%	4 906 662	7.4%	2 031 782
By-product	663 408	2.7%	1 402 438	1.2%	739 030
Others	2 806 337	11.5%	4 840 846	4.8%	2 034 509
Total	24 300 167	100.0%	38 014 038	100.0%	13 714 134

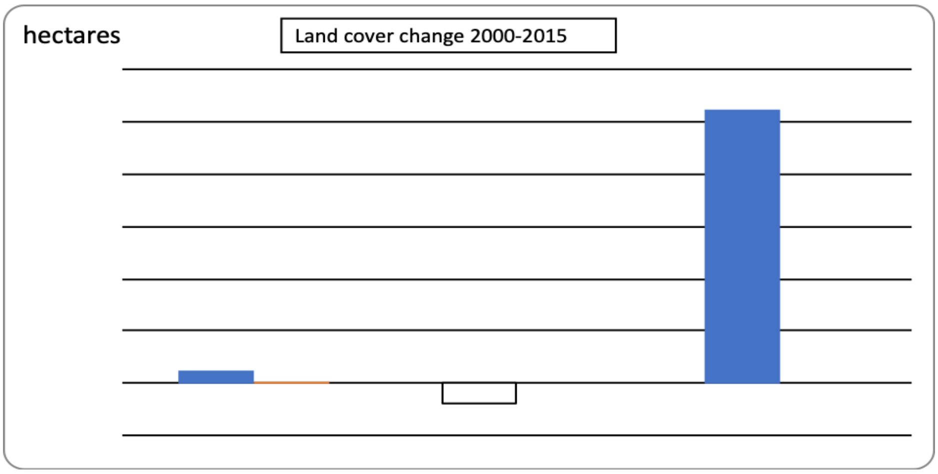
Source: CSA 2000; CSA 2015.

Table 4.28. Land cover change and animal feed holders

2000-2015 Land cover change in hectares	
Crop land, irrigated or post flooding	24 312
Crop land, rainfed	-39 319
Grass land	524 525
2000-2015 Change number of holders	
Crop residue	4 147 865
Grass fodder/grazing	4 489 214

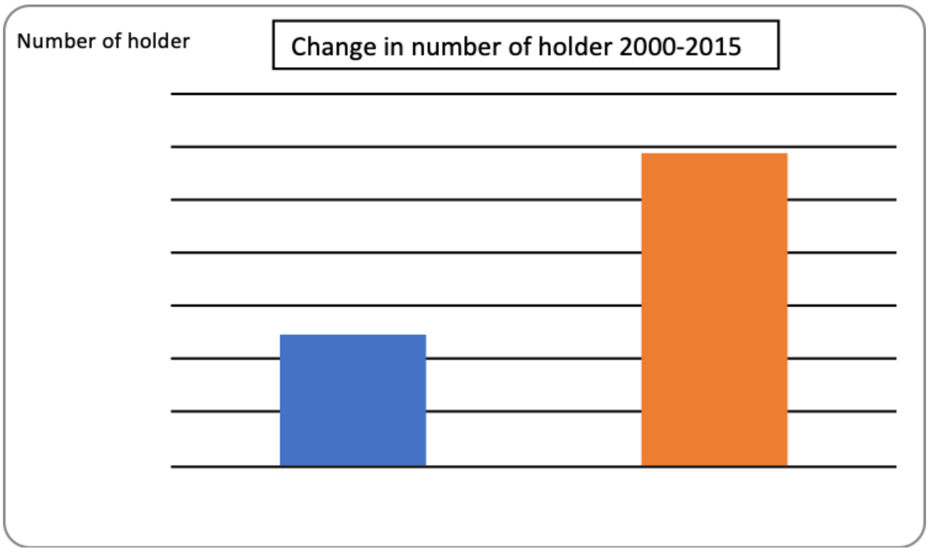
Source: Raw data used from Catholic University of Louvain-Geomatics, ESA; CSA 2000; CSA 2015.

Figure 4.17. Land cover change between 2000 and 2015 in Ethiopia



Source: Raw land use data used from Catholic University of Louvain-Geomatics and ESA.

Figure 4.18. Animal feed holder changes between 2000 and 2015 in Ethiopia



Source: CSA 2000; CSA 2015.

Linkages with bioenergy

Total national biomass fuel consumption and cover change

Total national consumption of wood for energy purposes (including charcoal equivalent of wood) is estimated at 105.2 million tons per year, with 5.7 million tons of charcoal in 2013 (Table 4.29). It is increasing each year. The regional shares of wood (including charcoal equivalent of wood) consumption in Oromiya, SNNPR and Amhara are 37 per cent, 25 per cent and 23 per cent respectively. Regions with high charcoal consumption have been exposed to high shrubland degradation (Table 4.29). The national wood removal increased sharply from 1990 to 2015 (Table 4.30), which shows that the declines in woodland and shrubland were strongly linked to the high use of charcoal and wood for energy production in the country.

Table 4.29. Total national consumption of biomass fuels (2013) and shrubland cover change, 2000-2015

Region	Round wood	Branches, leaves and twigs	Charcoal as wood	Total wood	Total wood	Residues	Dung	Charcoal	Shrubs land cover change (2000-2015)
	tons/yr	tons/yr	tons/yr	tons/yr	%	tons/yr	tons/yr	tons/yr	Area in Hectares
Addis Ababa	684 228	-	1 060 439	1 744 667	2%	-	39 961	212 088	-900
Afar	830 552	-	1 195 154	2 025 706	2%	-	49 364	239 031	+6300
Amhara	9 549 847	8 042 277	6 603 169	24 287 123	23%	3 867 504	8 221 892	1 339 000	-153000
Bsg	419 308	271 709	202 893	893 911	1%	427 246	188 435	40 579	-53000
Diredawa	219 831	54 698	359 246	633 774	1%	39 971	29 548	71 849	-128
Gambela	181 653	74 736	96 236	364 659	0%	67 069	44 966	20 735	+1400
Harari	136 728	38 463	225 685	400 876	0%	28 108	21 501	45 137	+328
Oromiya	17 812 299	11 070 636	9 921 703	38 804 638	37%	7 571 451	6 261 813	1 984 341	-108700
SNNPR	15 264 304	7 185 536	3 564 630	26 014 470	25%	7 539 192	2 229 843	712 926	-65200
Somali	2 520 644	211 155	3 203 569	5 935 369	6%	152 929	220 755	614 467	-56500
Tigray	614 995	1 284 533	2 167 743	4 067 271	4%	31 256	5 511 309	433 549	-58500
Total	48 234 389	28 233 742	28 600 468	105 172 465		19 724 725	22 819 390	5 713 700	-495928

Source: Raw land use data used from Catholic University of Louvain-Geomatics and ESA and Geissler *et al.* 2013.

Table 4.30. National total wood removal from the forest for different purposes, including energy in Ethiopia

Year	Total wood removal (million m^3)	Year	Total wood removal (million m3)
1993	78.48	2003	94.53
1994	80.77	2004	95.96
1995	82.53	2005	97.41
1996	83.65	2006	98.63
1997	85.50	2007	100.00
1998	86.53	2008	101.42
1999	88.24	2009	102.81
2000	89.30	2010	104.21
2001	91.28	2011	104.21
2002	92.60		

Source: FAO 2015.

Sustainable woody biomass yield

The total wood product demand in 2015, measured by the volume of wood consumed in the country (production import-export) was around 130.3 million m^3 of roundwood equivalent. Approximately 92.3 per cent of this is in the form of wood fuel and the rest is in the form of industrial wood (MEFCC 2018). The annual volume of wood harvested for wood fuel was around 120.4 million m^3 of roundwood equivalent in 2015 (115.024 million m^3 as firewood and 5.408 million m^3 for conversion into charcoal) (MEFCC 2018). The sustainable supply of wood fuel from natural forests and woodlands is only 32.1 million m^3 of roundwood equivalent (MEFCC 2018). Harvest per hectare is not available.

Currently, more than 90 per cent of the domestic supplies of fuel wood come from diverse sources such as natural high forests and woodlands, industrial plantations and private forests (trees outside forests including woodlots) (Table 4.31).

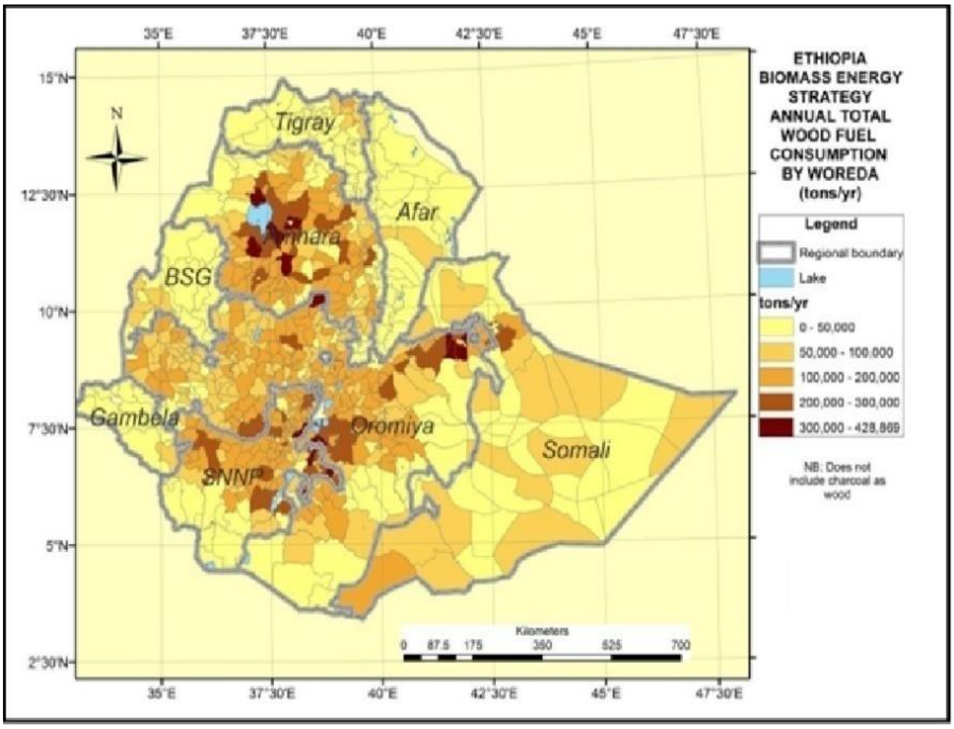
Table 4.31. Estimate of wood fuel supply in Ethiopia

Forest type	**Estimated annual supply of fuel wood in roundwood equivalent ($x10^6$ m^3)**	**Proportion**
Woodlots	6.6	5.48%
Natural forests and woodlands (sustainable supply)	32.1	26.66%
Peri-urban energy plantations	0.08	0.07%
Public plantations	0.07	0.06%
Area exclosures	1.64	1.36%
Woodfuel from waste	0.17	0.14%
Import	0.000279	0.00%
Unknown source (1)	79.74	66.23%
Total	120.40	100%

(1) This is most likely the volume extracted from natural forests through unsustainable harvest.
Source: MEFCC 2017; MEFCC 2018.

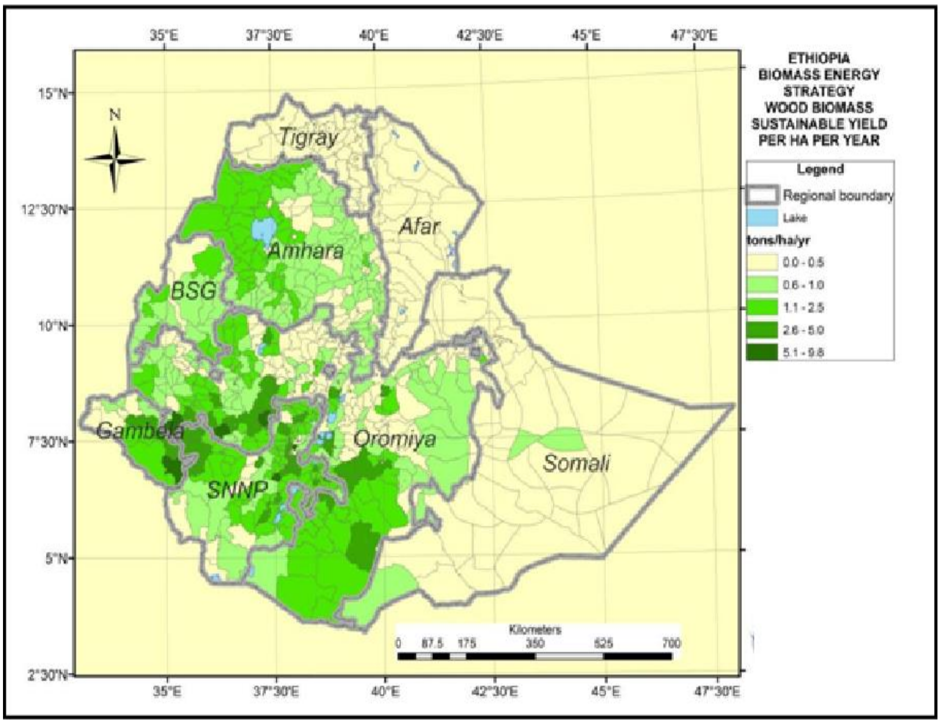
Unsustainable extraction of wood from forests and woodlands for the purposes of fuel wood and charcoal has contributed greatly to the loss of forest resources and to widespread degradation and deforestation. This in turn has contributed to a sustainable supply gap for the volume of fuel wood needed today (MEFCC 2018). The loss of acacia woodland in the Central Rift Valley area is generally associated with charcoal production and firewood extraction. Acacia species are the favoured sources for charcoal production given their smooth combustion and better energy yield.

Map 4.16. Annual consumption of woody biomass by woreda (tons/yr)



Source: Geissler *et al.* 2013.

Map 4.17. Annual natural sustainable supply of woody biomass by woreda (tons/ha/yr)



Source: Geissler *et al.* 2013.

Total area of land for solid biomass used for energy purpose
Areas of planted forests have increased compared to previous decades in different regions of Ethiopia. The total land area used to produce solid biomass for energy purposes is an estimated at 972,000 ha (Table 4.32). The bulk of these plantation forests are small-scale private plantations and woodlots. Accordingly, the solid biomass production of these areas is increasing, and wood from these plantations is supplying the national biomass fuel use today. The national estimate of yield supplied was 58.3 million tons in 2000. However, the estimate for 2013 is 110.2 million tons. The near doubling is caused by the fact that plantations have been supplemented by additional plantings since 2000.

Table 4.32. Extent of forest plantations supplying the national biomass fuel use

Regional state	Industrial plantation	Non-industrial small-scale private plantation	Per-urban energy planation	Total
Oromia	78 800	27 800	26 700	133 300
Amhara	44 600	639 400		684 000
SNNPR	27 300	64 000		91 300
Tigray	39 700	23 700		63 400
Total	190 400	754 900	26 700	972 000

Source: Bekele 2011.

Solid biomass from degraded or contaminated land
Producing solid biomass on contaminated land could improve both the economic and environmental outlook of bioenergy, as it would bring a positive economic return from contaminated land without replacing food crops. A literature assessment was conducted to identify any attempts or the possibility of biomass production on contaminated land in Ethiopia; however, no information was found in this regard.

4.8.6 Main conclusions and recommendations

Synthesis of the findings
Analyses of forest and wood land cover change were conducted using secondary data sources. A major change in land cover has occurred for the past many years. Across the country, farmland is encroaching on the landscape at an alarming rate. In line with this, a change in fuelwood consumption and an associated increase in deforestation is leading to environmental challenges in the country.

Practices and policies to improve sustainability
Based on the above conclusion the following recommendations are presented:

- Land distribution and affordable energy sources are among the most important development issues in Ethiopia. Planning and implementing an appropriate strategy for land use for forestry and biomass energy utilization is important. Dedicating land specifically to biomass production could increase the amount of biomass available for energy generation and other applications across the country.
- Establishment of a continuous land cover monitoring system is crucial to have up-to-date and accurate trends in land-use change.
- Disseminating new efficient bioenergy technologies and implementing the policies and research findings are valuable to achieve sustainable development.

Future monitoring

The result of this indicator is based on secondary information from different sources that provide a starting place in broadening the issue of land use and land-use change related to bioenergy feedstock production in Ethiopia. We recommend further study based on primary data combining household surveys within the next 5 to 10 years.

4.8.7 References

Agricultural Sample Survey (2007/08). *Report on Livestock and Livestock Characteristics (Private Peasant Holdings)*. Statistical Bulletin 417, Volume II, Addis Ababa.

Agricultural Sample Survey (2014/15). *Report on Livestock and Livestock Characteristics (Private Peasant Holdings).* Statistical Bulletin 578, Volume II. Addis Ababa.

Bekele, M. (2011). Forest plantations and woodlots in Ethiopia. *African Forest Forum* 1, 52.

Ethiopian National Energy Policy (2015). Ministry of Water, Irrigation and Energy. Addis Ababa.

Food and Agriculture Organization of the United Nations (2001). *Trees Outside forests: Towards Rural and Urban Integrated Resources Management.* Rome. ftp://ftp.fao.org/ docrep/fao/005/y1785e00.pdf.

Food and Agriculture Organization of the United Nations (2009). *Eucalyptus in East Africa: the Socio-Economic and Environmental Issues.* Food and Agriculture Organization. Addis Ababa.

Food and Agriculture Organization of the United Nations (2010). *Global Forest Resources Assessment of 2010, Country Report Ethiopia*. Rome. www. fao.org/forestry/ fra/fra2010/en/.

Food and Agriculture Organization of the United Nations (2015). *Global Forest Resources Assessments*. Rome.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Global Forest Research Assessment (2015). *Terms and Definitions.* Forest Resources Assessment Working Paper 180.

Institute of Biodiversity Conservation (2005). *National Biodiversity Strategy and Action Plan*. Addis Ababa.

Kelemu, K. and Tadesse, W. (2010). Analysis of Eucalyptus role in the livelihoods of rural households. In: G, L., Tadesse, W., Tolosana, E. and López, R. (eds.). *Proceedings of the Conference on Eucalyptus Species Management, History, Status and Trends in Ethiopia*, 15th-17th September 2010. Addis Ababa, Ethiopia, pp. 53-61.

Lemenih, M. and Bekele, M. (2008). *Participatory Forest Management Best Practices, Lesson Learnt and Challenges Encountered: The Ethiopian and Tanzanian Experiences*. Farm Africa, Ethiopia. Food and Agriculture Organization of the United Nations. 66.

Ministry of Environment, Forest and Climate Change (2016). *The Contribution of Forests to National Income in Ethiopia and Linkages with REDD+,* Executive summary.

Ministry of Environment, Forest and Climate Change (2017). *Ethiopia forest sector review. Technical Report. Focus on commercial forestry and industrialization.*

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Program, Ethiopia. Volume I: Situation Analysis*. Addis Ababa.

Moges, Y., Eshetu, Z. and Nune, S. (2010). *Ethiopian Forest Resources: Current Status and Future Management Options in View of Access to Carbon Finances.* A Report Submitted to Ethiopian Climate Research and Networking and United Nations Development Programme. Addis Ababa.

Teketay, D. (2001). Deforestation, wood famine, and environmental degradation in Ethiopia's highland ecosystems: urgent need for action. *Int. Conf. African Dev. Arch* Pap. 3.

Wassie, A., Teketay, D. and Powell, N. (2005). Church forests in North Gonder administrative zone, Northern Ethiopia. *For. Trees*.

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

4.9.1 Researcher(s)

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4.9.2 Description

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.

4.9.3 Measurement unit(s)

Percentage

4.9.4 Overall methodology of the implementation

Land tenure has an important place in the economic, political, social and cultural history of Ethiopia. It has long been the subject of debate among farmers, policy makers, researchers and the public at large and is viewed not only as a source of livelihood, but also as a source of political and economic power (Tesema 2008). Thus, obtaining relevant and quantified data and information linked to land can be challenging. For this reason, it was not possible to conduct a field assessment of indicator components 9.1 and 9.2. A quantitative measurement of the indicator also was not possible due to shortage of data. However, an in-depth review of relevant secondary sources was carried out on the legislative framework related to land tenure and access to and on conflicts on land associated with new bioenergy production, as summarized and presented in the sections below. Furthermore, a concise description was made of legal systems linked to land tenure, ownership and use related to solid biomass and biogas production.

4.9.5 Key findings

NATIONAL LEVEL

Legislative framework related to land tenure
A land tenure system is a product of historical and cultural factors. It comprises the customary and legislative rights that individuals or groups have to land and related resources, such as trees, minerals, pastures and water. Land tenure also reflects the resulting social relationships (Kuhnen 1982), the possession rights associated with each parcel of land (Zerga 2016) and the rules and regulations about holdings and use of land in a society – all of which constitute the land tenure system (Bahru 1998). It includes allocation, transfer, use and management. When land tenure is secure, land can be a cornerstone for economic growth and an incentive for investment.

Each country has developed specific land tenure concepts that are based on historical and current values and norms. These concepts, which have often been shaped by an evolutionary process, determine the present tenure systems. In Ethiopia, land has been the central means by which rural communities have been tied to their livelihoods, and land tenure includes claims on land, with the level of enforcement ranging from national laws to local village rules, supported in turn by national regulatory frameworks. The land administration framework is dispersed in the legal documents of Ethiopia, which can be divided into the following historical stages (as summarized in Table 4.33):

land tenure during the pre-1975 period, land tenure during the Derg regime and land tenure during the Ethiopian Peoples' Revolutionary Front (EPRDF) regime.

Table 4.33. Historical development of land tenure in Ethiopia, pre-1975 to now

Period	Reform	Details
Pre-1975	Land policy	During this period, land was assumed to be an issue of power and governance. The land tenure system varied from region to region due to the diverse geographical and cultural settings and the different socio-political events that occurred in different parts of the country. Common forms of land tenure included communal (rist), grant land (gult), freehold or sometimes referred to as private (gebbar tenures), church (samon) and state (maderia, mengist) tenure regimes.
Derg regime (1975 to 1995)	Proclamation	Full ownership land rights are in the hands of the state. Land administration was vested in the then Ministry of Land Reform and Administration through Peasant Associations at the grassroots levels.
*EPRDF** regime (1995 to now)	Constitution	The right to ownership land is exclusively given to the State and to the peoples of Ethiopia.

*Ethiopian Peoples' Revolutionary Democratic Front

The current land tenure system

As a basic principle of the current land tenure system of Ethiopia, land property rights are vested in the state and usufruct rights are given to farmers.

The Rural Land Administration Proclamation No. 89/1997 vested the regional governments with the power of land administration. The regional governments enact laws on land administration, land utilization, taxation and other tenure-related polices.

The Federal Rural Land Administration and Land Use Proclamation No. 456/2005 was also enacted for the purpose of ensuring tenure security; strengthening property rights of farmers; sustainably conserving and developing natural resources; establishing a land database; and establishing an efficient land administration in the country. The re-enactment of urban lands Proclamation No. 272/2002 provides the legal basis for temporary urban land leases for various investment purposes.

Through Proclamation No. 89/1997, significant authority and responsibilities, including the enactment of laws on land administration, land utilization, taxation and other tenure related polices, for land administration were transferred to regional governments. Furthermore, regional governments were given the authority to provide land certification to improve land tenure security. Accordingly, the four regional states of Oromiya, Amhara, Tigray and the SNNPR region have carried out land registration and issued land holding certificates to rural landowners (farmers). A detail cadastral survey is also under way in these regions, with the aim of providing landowners with land holding maps. This ongoing initiative has helped rural communities to feel more secure about their land.

Because the current land tenure is constitutional, it is difficult to anticipate radical land reform measures from the government in the foreseeable future. However, the ongoing land certification process (issuing of land holding certificates), which is more administrative, should continue to improve the tenure security of rural inhabitants. It should be strengthened constitutionally and legally to provide proper value of privatization so that farmers may sell their land.

BIOGAS

The construction of biogas digesters does not require much space (around 16 m^2 for the 6 m3 biodigester). The linkages between biodigester implementation and land tenure can be illustrated by the impacts on forestry. Both biogas users and experts from different offices believe that biogas has greatly reduced the use of firewood, contributing to improvement in forest coverage. Survey respondents were asked to evaluate the forest coverage in their locality in the past few years. A considerable number of respondents (63 per cent) believe that the forest coverage in their locality is increasing (National Biogas Use Survey [NBUS] 2018).

The biggest increase in forest and bush coverage is reported in the Amhara and Tigray regions and the lowest in Oromiya region. One reason for increasing forest coverage in the localities is the shift in the use of alternative energy sources such as biogas, the electricity grid and solar power. Even though the increase in forest coverage cannot be fully attributed to the introduction of biogas technology, the biogas programme has contributed meaningfully because a majority of biogas users have fully or partially shifted from solid biomass to gaseous energy sources due to this programme.

The introduction of biogas technology has also strengthened area closure because users of the technology have changed their free grazing to a cut-and-carry animal feeding system. In the survey localities, the animals of biogas users spend day and night around the homestead because biogas users need the dung (the major biogas input) around their homes (MoWIE 2018).

SOLID BIOMASS

Land tenure and solid biomass production
According to the current constitution of the country, the right to ownership of land as well as the natural resources is solely vested in the state and in the people of Ethiopia. Accordingly, the natural forests have been owned by the state and administered by regional concerned bodies after the decentralization of 1991. Natural forests, therefore, are not available for private ownership by law. However, the new forest development, conservation and utilization proclamation (542/2007), which is accompanied by the country's forest policy and strategy on forest development, provides the framework for making fundamental changes to forest resource management. The new proclamation allows for forests to be designated as either private, state, community or association owned. Categories of forest resources ownership are shown in Table 4.34.

Table 4.34. Categories of forest resources ownership and their total land area used in Ethiopia

Category of ownership	Area (1 000 ha)	% of total land area
Public plantation forests	190.4	0.2
Public natural forests	11 996.0	11.2
Joint forest management	300.0	0.3
Private plantation and woodlands	602.8	0.7
Community woodlots	152.1	0.2

Source: Bekele 2011.

In the last two decades, the commitment to empowering local communities and decentralizing decision-making to local governments has been growing. A new management system is now in place in which local people have defined control with rights and obligations over forest resources, leading to more sustainable use. In this regard, communities living in and around some forest areas have already shown interest in and capability to manage the forests. However, the following limitations are considered as shortfalls:

- *Limited access to forest resources*: Although the concept of forest conservation and development is supported by the local communities, they are restricted to use only non-timber forest products such as coffee, honey, wild fruits, traditional medicinal plants and mushrooms; bamboo, timber and other woody products are not allowed in and around the forest areas. This has led to the degradation of forest lands through clearing, overgrazing, cultivation on forest lands and forest land burning.

- *Lack of access to collateral to get bank loans*: In Ethiopia, the government provides collateral loans to investment projects. However, in forestry there are no such mechanisms to involve the private sector in plantations or related bioenergy development sectors.

- *Lack of forest land certification*: The government is implementing a land certification programme to improve the tenure security of rural inhabitants for their agricultural production. However, such a certification programme is not available in forestry. Thus, assuring tenure security in the full sense of privatization of forest lands is still recognized as a shortfall.

Established legal procedures for acquiring land
Land administration is a system implemented by the state to record and manage rights over land. In Ethiopia, all land is public property and belongs to the state. Land cannot be bought, but it can be leased for a certain number of years. Regional governments are the principal administrators and regulators of land, including the assignment and granting of use-rights, and regional land-use planning and administrative authorities are responsible for recording, documenting and administering use-rights. Securing land in rural Ethiopia involves the concurrence of public authorities at some level: local (kebele or woreda), regional or national.

The regional governments deliver land, based on the federal law and their own laws. The required land is given to an investor within 60 days after receiving an application for allocation of land for an approved investment. Most of the time, the lease is related to urban land and landholdings up to 99 years, and payment within 10-99 years. However, if rent is related to rural land and the landholdings have a shorter period than 99 years, payment is on an annual basis for the whole contract period.

There are three procedural ways to acquire land, known by the people or the person being advised by experts when needed:

1. When you know in which area you wish to acquire land, the regional investment office can assign locations that are already prepared for different purposes.
2. When the specific location you have identified is owned by local farmers and not yet prepared by the government, the regional investment office can decide to negotiate with the farmers.
3. When the specific location you have identified as suitable is not one of the locations especially assigned for investment by the regional states, the regional investment office can write a letter to the local kebele about your land application. You will be the one to conduct all further negotiations and you yourself will sign the contract.

The Investment commission, in cooperation with the concerned regional government entities, facilitates and follows up on the allocation of land for approved investments, especially for foreign investors. Investors who intend to invest in forestry-related projects are given priority to acquire land at a reduced lease price.

Table 4.35. Different rental prices of rural land for agricultural projects in different regional states

Regional state	Minimum average price (Birr/ha)	Maximum average price (Birr/ha)
Amhara	14.21	79.37
BeniShangul	15.00	25.00
Gambella	20.00	30.00
Oromia	70.00	135.00
SNNP	30.00	117.00
Tigrai	30.00	40.00

Source: Dessalegne 2011.

Land disputes and conflicts

Weak customary institutions, population growth, frequent drought, resource degradation, and encroachment or expropriation of rangelands are some of the causes of conflicts and disputes of land in Ethiopia (Hundie 2006; Michael *et al.* 2005; Rahmato and Asefa 2006). To some extent, disputes occur related to biomass fuel collection from private lands or plantations. However, the constitution allows for the resolution of disputes between individuals using customary laws and practices, which may apply to land-related disputes. The state has generally ignored the administration and adjudication of pastoralist tenure. While this has resulted in the loss of crucial rangeland to crop cultivation, sometimes as a result of government expropriation, it has meant a continuing role for clan-based tenure regimes (World Bank 1999; Crewett *et al.* 2008).

The situation of smallholder farmers and rural communities

In Ethiopia land has been the centre of power and the source of the economy (Zerga 2016). Therefore, control over its ownership has been a political issue and interest of the state. However, small land holdings with subsistence production have dominated the farming system over the century (Aredo *et al.* 1995). The major challenge facing smallholder farmers in Ethiopia is environmental degradation manifested in the form of deforestation, which has a link to insecurity and tenure of land.

Apart from shortage of wood products, deforestation is becoming the main reason for land degradation and the subsequent decline in agricultural productivity and the resulting poverty observed among the rural communities. Efforts have been made to avert poverty; however, it remains unresolved. Where appropriate, land consolidation, exchanges or other approaches must be considered to help smallholder farmers improve their holdings to sustain rural development in the country. Also, there should be encouragement and facilitation of land banking practices to provide opportunities for smallholder farmers as a group to acquire large areas of land for rural investments. The practice will allow them to continue, and even increase, production in both agriculture and bioenergy.

Incentives for solid biomass developments

The government of Ethiopia has allocated some plantations for community management and offers various incentives for plantation development under different land tenure systems (Table 4.36).

Table 4.36. Incentives for plantation development for solid biomass production in Ethiopia

Type of incentive	Brief description	Source and period	Target group	Outcomes and shortcomings
Direct	Long term leasing for land to be used for plantation establishment	Government and for 25 years	Private investors	Encourage the private sector to involve in planation forestry
Direct	Free supply of seedlings	Government and during plantation season	Farming communities and urban dwellers	Encourage the farming communities to plant trees
Indirect	Free markets and pricing policy	Government	Private investors in tree planting	Plant more trees due to market value of trees
Direct	Opportunity to get loan from banks	Government and credit associations	Private investors in forestry	Encourage for tree planting
Direct	Handling over of woodlot plantations to farmers	Government	farmers	
Direct	Sharing of revenue with communities from sale of forests products from plantation forests	Government	Farming communities in and around the forest	The forests are better conserved and more area coverage
Direct	Free from tax payment on imports for forestry related activities	Government, as long as they are involved in the work	Private investors	Motivate others to participate in the activity

Source: Bekele 2011.

Other initiatives

A Sustainable Land Management (SLM) project has been undertaken in Ethiopia since 2015 by the Ministry of Agriculture and Natural Resources (Emmanuel 2017). The aim is to enable land users to boost the economic and social benefits from the land while enhancing the functioning of the land through conserving and restoring forests, wetlands, dry lands and mountains (Fafchamps *et al.* 2002; Emmanuel 2017). So far, appropriate management measures such as terracing, pasture-land development and tree plantation have been applied on around 390,000 hectares of degraded land.

Consequently, the knowledge and skills of local communities on SLM have improved, and more than 500 local smallholder groups have established and are jointly managing land using sustainable methods. The groups also have been receiving advice and institutional support from trained experts from the respective districts in their vicinity and communities. There is a need to scale up such practices to improve land tenure and rights for sustainable land management and development in the country. This can be achieved through interactions between smallholders and decision makers at the national, regional, and local levels.

4.9.6 Conclusions and recommendations

Synthesis of the findings

In Ethiopia, land has been the central means by which the rural community has been tied to their livelihoods. Land tenure includes claims on land, with the level of enforcement ranging from national laws to local village rules, supported in turn by national regulatory frameworks. According to the current Constitution, the right to ownership of land as well as of natural resources is solely vested in the state and in the people of Ethiopia. The type of property right for 85 per cent of the population is usufructuary right (private user-rights) on public land.

The average land holding size of farmers has been estimated at around 0.5 hectares; it is reported to be diminishing with the ever-growing population and the accompanying redistribution of land.

Although a quantitative assessment of the total land used for solid biomass production was not undertaken, the qualitative assessment has provided interesting information. Currently, the government of Ethiopia has allocated forests lands for community management and several incentives for plantation development under different land tenure systems. However, securing land for this purpose involves the concurrence of different authorities at some level, indicating that there is a need to improve the land administration systems.

Practices and policies to improve sustainability
Proper land tenure and allocation of land for solid biomass production is the basic requirement for bringing sustainable bioenergy production into the picture. However, the land belongs to the state. It cannot be bought, but it can be leased for a certain number of years. Thus, policy and legal reform should ensure the security of land tenure for smallholder farmers and rural communities.

Future monitoring
Modern bioenergy development is critical for Ethiopia to ensure energy security as well as to contribute to poverty reduction and a climate-resilient green economy. Therefore, it will be crucial to monitor the effect of land tenure and access on the sustainability of bioenergy. For this study, secondary data sources (survey results) were employed. For future monitoring, a broader sample of households in a higher number of regions should be surveyed. In addition, better coordination and collaboration would be needed between the related competent governmental agencies and ministries (Ministry of Water, Irrigation and Energy; Ministry of Mines and Petroleum; Environment, Forest and Climate Change Commission; Ministry of Agriculture, etc.) which can provide the needed information to measure this indicator.

4.9.7 References

Aredo D. and Demake M. (1995). *Ethiopian Agriculture: Problem of Transformation.* Proceedings of the Fourth Annual Conference on Ethiopian Economy. Addis Ababa.

Bahru, Z. (1998). *A Short History of Ethiopia and the Horn*. Addis Abba.

Bekele, M. (2011). Forest plantations and woodlots in Ethiopia. *African Forest Forum Working Paper Series* 1, 12.

Bekele, M. and Kassa, H. (2012). Forest Policy, Strategies and Laws of Ethiopia: Opportunities and Challenges to Developing the Sector ... – PowerPoint presentation. 23-24 July 2012. Addis Ababa. http://nilebdc.wikispaces.com.

Crewett, W., Bogale, A. and Korf, B. (2008). *Land Tenure in Ethiopia: Continuity and Change, Shifting Rulers, and the Quest for State Control.* CAPRI Working Paper No. 91. September.

Dessalegn, R. (2011). *Land to Inverters: Large-scale Land Transfers in Ethiopia.* Forum for Social Studies. Available at: https://theredddesk.org/sites/default/files/resources/pdf/Ethiopia_Rahmato_FSS_2011.pdf.

Elias, W. and Shabbir, H.G. (2018). Potential of bioenergy production in Ethiopia based on available biomass residues. *Biomass and Bioenergy* 111, 77-87.

Fafchamps, M. and Quisumbing, A.R. (2002). Control and ownership of assets within rural Ethiopian households. *Journal of Development Studies* 38(2), 47-82.

Hundie, B. (2006). Property rights among Afar pastoralists of Northeastern Ethiopia: Forms, changes and conflicts. Presented at Survival of the Commons: Mounting Challenges and New Realities, the Eleventh Conference of the International Association for the Study of Common Property. Bali, Indonesia. June 19-23.

Kasimbazi, E. (2017). *Land Tenure and Rights for Improved Land Management and Sustainable Development.* UNCCD | Global Land Outlook Working Paper | LAND TENURE AND RIGHTS 3.

Kuhnen, F. (1982). *Man and Land*. Saarbrücken and Fort Lauderdale.

Michael, Y.G., Hagdu, K. and Ambaye, V. (2005). *Addressing Pastoralist Conflict in Ethiopia: The Case of the Kuraz and Hamer Sub-districts of South Omo Zone.* African Peace Forum, Ethiopian Pastoralist Research and Development Association, Interafrica Group, Saferworld.

National Biogas Users' Survey (2018). National Biogas Programme of Ethiopia. Ministry of Water, Energy and Electricity. Addis Ababa.

National Biogas Programme of Ethiopia (2015). *Report on Biogas Users' Survey.* Ministry of Water, Irrigation and Energy. Addis Ababa.

Rahmato, D. and Assefa T. (2006). Land and the challenge of sustainable development in Ethiopia: Conference Proceedings. Forum for Social Studies. Addis Ababa.

Shapiro, B.I., Gebru, G., Desta, S., Negassa, A., Nigussie, K., Aboset G. *et al.* (2017). *Ethiopia Livestock Sector Analysis.* ILRI Project Report. International Livestock Research Institute. Nairobi, Kenya.

SNV Netherlands Development Organisation (2018). National Biogas Programme of Ethiopia (NBPE). Addis Ababa, Ethiopia.

Tesema, T. (2008). The underlying causes and mitigation measures of deforestation: A critical assessment of the Ethiopian forest policies and strategies. BOKU. Vienna.

World Bank (1999). *Gender and Law: Eastern Africa Speaks.* The World Bank Group Africa Region. Finding No. 126. January.

Zerga, B. (2016). Land resource, uses, and ownership in Ethiopia: Past, present and future. *International Journal of Scientific Research Technology Engineering* 2, 17-24.

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

4.10.1 Researcher(s)

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4.10.2 Description

(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 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.

4.10.3 Measurement unit(s)

Tons; $; National Currency (Ethiopian Birr); and Percentage.

4.10.4 Overall methodology of the implementation

This indicator is aimed at measuring the impact of bioenergy use and its domestic production on the price and supply of a representative food basket in the context of relevant factors. It is particularly important in the case of the bioenergy crop production, such as cassava, which is directly included in the staple food crops. Indeed, bioenergy production could lead to a reduction in the domestic supply of staple crops available for food. On the other hand, bioenergy production may contribute to an increase in agricultural production, resulting in an increase in the domestic supply of staple crops for food. In addition, bioenergy production may alter the demand for inputs, such as fertilizers, that are used in the production of main staple crops, and therefore their price.

In principle, the measurement of this indicator consists of two main steps. The first step is the identification of the most significant food items in people's diets to be included in the food basket. The second step is the evaluation of the effects of bioenergy production and domestic use on the price and supply of a nationally determined food basket. This can be done with different levels of quantitative analysis, from discussions among experts up to modelling.

In Ethiopia, the expected impact of solid biomass and biogas on the price and supply of a national food basket is not evident since the biogas production in Ethiopia is from organic waste (animal dung) and not from specific energy crops. But some reflections remain relevant. They are proposed in the case of biogas, and specifically regarding how the bioslurry generated by the biodigester could have an impact on the price of the food basket of the households.

Various national data sets and reports were collected from different offices, and internet facilities were used. The main sources of information are the surveys conducted on the national biogas programme (National Biogas Programme of Ethiopia [NBPE] 2015; Netherlands Development Organisation [SNV] 2018). These surveys refer to a case study approach, collecting data in different woredas of four regions (Tigray, Amhara, Oromia and SNNPR).

4.10.5 Key findings

NATIONAL LEVEL

The representative food basket of Ethiopia can be described as follows. The most dominant food crops in the country are teff, maize, sorghum and wheat (Ethiopia Central Statistical Agency [CSA] 2017). The Ethiopian diet consists chiefly of cereals (maize, sorghum, teff), tubers and root crops (ensete, potatoes, sweet potatoes), pulses and oil seeds. The national staple 'injera' is typically made from teff, which is grown in the highlands, or sometimes from millet or sorghum. Despite a large livestock population, dairy and meat supply is limited, with consumption of these products especially low in rural areas, except in nomadic pastoralist districts (Somali and Afar) where milk is a major component of the diet, consumed 4-5 days a week compared with 1.5 days on average nationally (World Food Programme 2014).

BIOGAS

The bioslurry produced by the biodigester can have positive impacts on agricultural production. According to the second round of surveys conducted by SNV on the national biogas programme (SNV 2018), biogas users have reduced the use of chemical fertilizer by 50 per cent. Taking into account the reduction in the use of fertilizer by biogas owners as well as the increase in the cost of fertilizer over years, the average saving from the cost of fertilizer for a farmer was 35 per cent (NBPE 2015). At the household level, the use of the bioslurry as a fertilizer contributed to reducing the price of the food by reducing the purchase of chemical fertilizer.

Most households use the slurry for garden vegetables such as onions, tomatoes, peppers and potatoes (Table 4.37). Around 40 per cent of the survey participants also indicted that they use the slurry for maize production. A large proportion of households using the slurry have observed changes in their crop production: 54 per cent for crops in general, 82 per cent for wheat, 74 per cent for vegetables; lower results (6 per cent) were observed with chat growing (NBPE 2015).

In terms of use, around 67 per cent of the respondents apply the slurry directly to their farms while fresh, while 57 per cent make compost first and apply it, and only 7 per cent mentioned that they sell it (Table 4.38). The biggest use of the slurry is reported in SNNPR where 95.6 per cent mentioned that they directly apply the liquid and 82.2 per cent make compost out of it and apply it as fertilizer. On the other hand, respondents in Amhara reported to sell slurry because biogas was promoted among people who are engaged in cattle husbandry and cattle fattening in urban areas. This people do not have farmland and tend to sell the slurry for others (SNV 2018).

Finally, biogas is becoming the main motivation for the increase in number of animals (SNV 2018). Thirty-three per cent of respondents said that the number of animals in their households has increased, with the highest number of households with increased animals observed in SNNPR (52 per cent) followed by Amhara (37 per cent) and Tigray (30 per cent) (Figure 4.19). The lowest reported increase in the number of animals is in Oromia (11 per cent). Talking about the reasons for the increases, 34.8 per cent of respondents mentioned the need for dung, 7.1 per cent mentioned the existence of breeding opportunities, and 5.7 per cent mentioned the availability of grazing land and water. On the other hand, 16.5 per cent of respondents mentioned that the number of animals has decreased due to lack of animal feeds (SNV 2018).

Table 4.37. Type of crops grown using slurry and the change in production

Type of crop grown	No. of households for whom the type of crop changed due to slurry	No. of households with change in production due to slurry	Percentage of households with production change
Vegetable	27	20	74%
Fruits	38	19	50%
Wheat	55	45	82%
Teff	46	26	57%
Coffee	15	6	40%
Barley	47	32	68%
Chat	22	2	9%

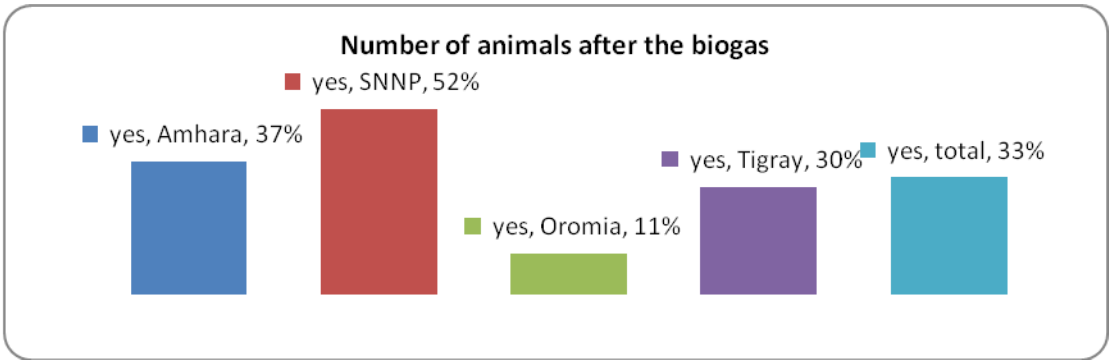
Source: NBPE 2015.

Table 4.38. Purpose of the bioslurry (%)

Slurry utilization	Amhara	SNNPR	Oromia	Tigray	Total
Use it fresh as liquid organic fertilizer	58.5%	95.6%	58.3%	56.3%	67%
Make compost with it first, then use as fertilizer	68.3%	82.2%	33.3%	43.8%	57%
Use it as fertilizer after it is solid and/or dry	70.7%	60.0%	8.3%	0.0%	35%
Sell it fresh and liquid to other people	29.3%	0.0%	0.0%	0.0%	7%

Source: National Biogas Programme of Ethiopia as described in NBPE 2015; SNV 2018.

Figure 4.19. Biogas impact on the number of animals (%)



Source: National Biogas Programme of Ethiopia as described in NBPE 2015; SNV 2018.

4.10.6 Conclusions and recommendations

Synthesis of the findings

At the national level, no change in the domestic food markets caused by production of biogas is observed in Ethiopia. This is normal: biogas production in Ethiopia is still limited to some woredas in certain regions such as Tigray, Amhara, Oromia and SNNPR. In addition, the biogas production is made from animal dung and not from a feedstock specifically grown for energy purposes. In other words, the changes in the demand, supply and prices of the national food baskets in Ethiopia are independent of the current biogas production. Rather, they are driven by inflation and other factors.

However, at a household level, biogas production has a positive effect on crop productivity in households that use the slurry as a substitute for chemical fertilizer. Moreover, the cost of fertilizer used by households was reduced by 35 per cent thanks to the use of the bioslurry resulting from biogas digesters for energy production. This implies that the replacement of chemical fertilizers by slurry can help to reduce the total costs of growing the main food basket. There is also good reason to say that promoting biogas production may result in an increase in the number of livestock owned by households participating in biogas production. But due to lack of animal feed and fodder, it becomes difficult for them to greatly increase their livestock production.

Practices and policies to improve sustainability

There is high potential for biogas production in Ethiopia, because of the existence of large numbers of livestock in the country. An effective policy is needed to promote the installation of biodigesters and the production of biogas from organic waste available in the country. The increase in societal awareness may increase biogas production along with livestock production, at the expense of other less productive crops. This leads farmers to become more productive. As the biogas sector continues to expand, these issues should be closely monitored.

Although there is high potential for biogas production in the country, production currently remains very minimal and is limited to some pilot woredas in four regional states. An effective policy is needed to promote the installation of biodigesters and the production of biogas from organic waste available in the country. This has a direct effect in increasing the productivity of crops used in the staple food basket in the country. It also contributes to a reduction in the cost of chemical fertilizer and its replacement by slurry from the biodigester. The increase in livestock production is also very important in realizing the sustainability of animal dung-based biogas production, given the high potential for production due to the large presence of livestock in the country. It is important to increase the availability of livestock fodder for the farmers.

Future monitoring
In Ethiopia, comprehensive economic data on the price and supply of the national food basket are scarce. It would be very useful to develop this knowledge. Assessing the impacts of bioenergy on the price and supply of the national food basket will become essential as the bioenergy sector expands. Further guidance should be developed to support the implementation of this indicator, especially in relation to the analysis and interpretation of its results. This assessment is very skill and data intensive, and the use of models such as the Aglink-Cosimo may be needed. This model is managed by the Secretariats of the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO). It is used to generate the OECD-FAO Agricultural Outlook and policy scenario analysis. The capacities of Ethiopia in using this model would need to be strengthened for future monitoring.

4.10.7 References

Ethiopia Central Statistical Agency (2017). *Report on Area and Production of Major Crops, Agricultural Sample Survey Volume I*. Addis Ababa.

National Biogas Programme of Ethiopia (2015). *Report on Biogas Users' Survey (BUS).* SNV Netherlands Development Organisation. Addis Ababa.

National Biogas Programme of Ethiopia (2018). *Presentation of Report on National Biogas Program of Ethiopia*. SNV Netherlands Development Organisation. Addis Ababa.

SNV Netherlands Development Organisation (2018). *Report on National Biogas users' Survey, 2018.* Addis Ababa; National Biogas Programme of Ethiopia.

World Food Programme (2014). *Comprehensive Food Security and Vulnerability Analysis (CFSVCA), Ethiopia.* Ethiopia Central Statistical Agency and World Food Programme. Addis Ababa.

4.11 Indicator 11. Change in income

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4.11.1 Description

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 feed stocks, 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 percentage (for share or change in total income)

4.11.3 Overall methodology of the implementation

Employment and wages in the bioenergy sector can be important drivers of rural and social development. In addition, wage levels provide an important indication of the labour conditions enjoyed by people employed in this sector in relation to comparable sectors. In addition to wage income, self-employment is another important source of income that can be associated with bioenergy production.

In addition to the analysis of wages (sub-indicator 11.1), a special focus was on the assessment of the benefits associated with the own consumption of biogas and modern biomass (sub-indicator 11.2). Secondary data collected from four regions of the country (Oromia, Amhara, SNNPR and Tigray) were used, based on surveys of the sector. Various study reports obtained from the internet, project documents and theses were used.

4.11.4 Key findings

BIOGAS

The study covered four major regional states of Ethiopia: Tigray, Amhara, Oromia, and SNNPR. These regions are home to roughly 70 per cent of the livestock and over 70 per cent of the human population (Mengistu *et al.* 2016).

Wages along the biogas value chain
In Ethiopia the actors involved in the biogas value chain are: biogas fundraisers / providers, skilled masons, managers, technicians and extension staff (Netherlands Development Organisation [SNV] 2007). The analysis was focused on masons, given their important role in the success of the biodigester programme. One of the benefits of biogas plant dissemination is maximizing the masons' income. The masons' income before starting biogas installation was 300-500 birr per month. However, the monthly income is maximized and it is 1,300-6,000 birr as shown in Table 4.39.

The amount of payment for masons to install a specified biogas plant in Ethiopia differs from region to region. In Oromia and SNNPR, the biogas owners pay 1,114-1,739 birr for masons depending on the volume of the plant (Table 4.40).

In Northern Ethiopia, the scarcity of wood fuel and associated problems are more severe. The use of biogas technology has significant contributions in improving the lives of rural people in these areas. It reduces the depletion of woody biomass through improving the efficiency of energy use and energy substitutions (Mulu 2016). The principal obstacle limiting the expansion and use of the technology by rural farmers is their inability to afford the full cost of biogas installations. To overcome the problem, government loans and subsidies are crucial and hence the masons are paid from the subsidy by the government (Table 4.39). According to Rogers (1983), subsidies enhance the speed and relative advantage of adoption. Subsidies lead to the adoption of technologies by individuals who would not adopt otherwise.

Table 4.39. Source and amount of masons' payment per region

Region	Digester (m3)	Source of payment (Birr)		Total
		Government	Owner of digester	
Tigray	4	2 000	-	2 000
	6	2 400	-	2 400
	8	2 600	-	2 600
	10	2 800	-	2 800
Amhara	6	2 300	-	2 300
	8	2 500	-	2 500
Oromia	6	2 360	1 114	3 474
	8	2 360	1 419	3 779
	10	2 360	1 739	4 099
SNNPR	6	2 200	1 114	3 314
	8	2 200	1 200	3 400
	10	2 200	1 400	3 600

Source: Yitayal 2015.

Table 4.40. Masons' income before and after installing biogas plants

Mason code	No. of digesters	Income (Birr/month)	
		Before biogas	After biogas
M1	30	300	6 000
M2	20	300	4 000
M3	12	300	2 400
M4	7	300	1 300
M5	5	500	1 335
M6	7	400-500	2 273
M7	7	400-500	2 273
M8	15	2 500	4 376

Source: Yitayal 2015.

Expenses saved by households

The benefits of domestic biogas are divided over multiple levels (micro, meso and macro) of society and differ in the extent to which they can be translated in direct economic gains (formal versus informal). Households gained direct benefits from domestic biogas through the reduced use of traditional fuel sources, access to clean energy, reduced workload and health improvement – all resulting in improved living conditions, from which women and children particularly benefited, and also through improved soil fertility owing to the use of quality bio-fertilizer and resulting in improved agricultural output (SNV 2007).

A study conducted in Amhara region indicated that before installation of biogas plant, households used an average of 153.26 kg of chemical fertilizer annually in their agricultural land with an annual expenditure of 1065.16 birr per household. After installation of biogas, due to use of bioslurry fertilizer, the average household chemical fertilizer consumption was reduced to 50 kg, or a saving of 103.26 kg of fertilizer per household (Zerhun 2015). This has an equivalent savings of 717.657 birr per household (Table 4.42). Biogas users have indicated overall that they have experienced a significant decrease in the use of chemical fertilizer after installation of biogas. So far, 682 birr in Tigray, 270 birr in Oromia and 300 birr in SNNPR have been saved per owner and year (Yitayal 2015).

Sales of the bioslurry could also generate revenues. For example, two farmers in Oromia have already started selling the slurry after making compost (Yitayal 2015). One sells it for 15 birr per 25 kg of compost, which supplements his cattle fodder, and the other sells it for 100 birr per container (the container is about equal to 70 kg). The latter has developed a surplus income of 3,300 birr by selling on average 33 containers per month. A small number of households, in Amhara, also sell the bioslurry and earn money from it; they are engaged in cattle husbandry and cattle fattening in urban areas, and they do not have farmlands and tend to sell the slurry for others (SNV 2018).

Regarding the economic comparison of wood fuels (firewood and charcoal) with biogas energy, a cost-benefit analysis was conducted using payback period. Biogas users have reduced their expenditure for firewood and charcoal by 45 per cent and 51 per cent respectively compared to non-biogas users (Haftu and Abel 2016).

Table 4.41. Estimated annual benefits and costs attributed to biogas installation

Benefit and cost	Annual benefits and costs in birr				Average benefit or cost in birr
	2011	2012	2014	2015	
Benefit from increased crop yield	-	3 663	3 905	2 717	3 429
Benefit from reduced use of firewood	-	180	168	78	142
Benefit from reduced use of charcoal	-	1 152	576	439	723
Benefit from reduced use of kerosene	72	0	0	0	72
Total benefit					4 366
Initial investment cost	12 308	-	-	-	12 308
Annual cost of investment (12% interest, 25 years	1 569	1 569	1 569	1 569	1 569
Average operating cost	293	293	293	293	293
Total cost					1 862
Net annual social benefit per biodigester					2 504
Net annual private benefit per biodigester (minus cost supported by subsidy)					3 717

Source: Berhe *et al.* 2017.

Table 4.42. Income (birr) saving from purchasing expenditure

	Type of resource	Average resource saved due to installation of biogas plant in kg/year or l/year	Equivalent amount in birr	Per cent
1	Firewood	2 528	3 833	50.4%
2	Charcoal	324	1 243	16.4%
3	Dung cake	1 380	1 542	20.3%
4	Kerosene	21	266	3.5%
5	Chemical fertilizer	103.26	718	9.4%
	Total		7 602	100%

Source: Zerhun 2015.

Charcoal

The past 15 years have seen a massive increase in the consumption of charcoal in all regions from 48,581 tons/year in 2000 to 4,132,873 tons/year in 2013. The charcoal production and marketing in Ethiopia has been informally organized and produced (Geissler *et al.* 2013). The majority of informal charcoal producers are poor pastoral/agro-pastoral and mixed farming households living in the dry lowlands of Ethiopia. These households produce charcoal regularly as their main or additional source of income to support their families (Ministry of Environment, Forest and Climate Change 2016). Bekele and Girmay (2013) also stated that the majority of charcoal producers in Ethiopia are found to be among the poor of the rural population with little or no land to support their livelihoods. With the exception of some women engaged in the retailing activity, in the majority of cases the charcoal business appears to be dominated by younger men, particularly landless youth.

Wages along charcoal value chain
Charcoal is among the most important and reliable cash income sources compared to incomes from semi-subsistence crop and livestock activities, which are subject to climatic and other calamities.

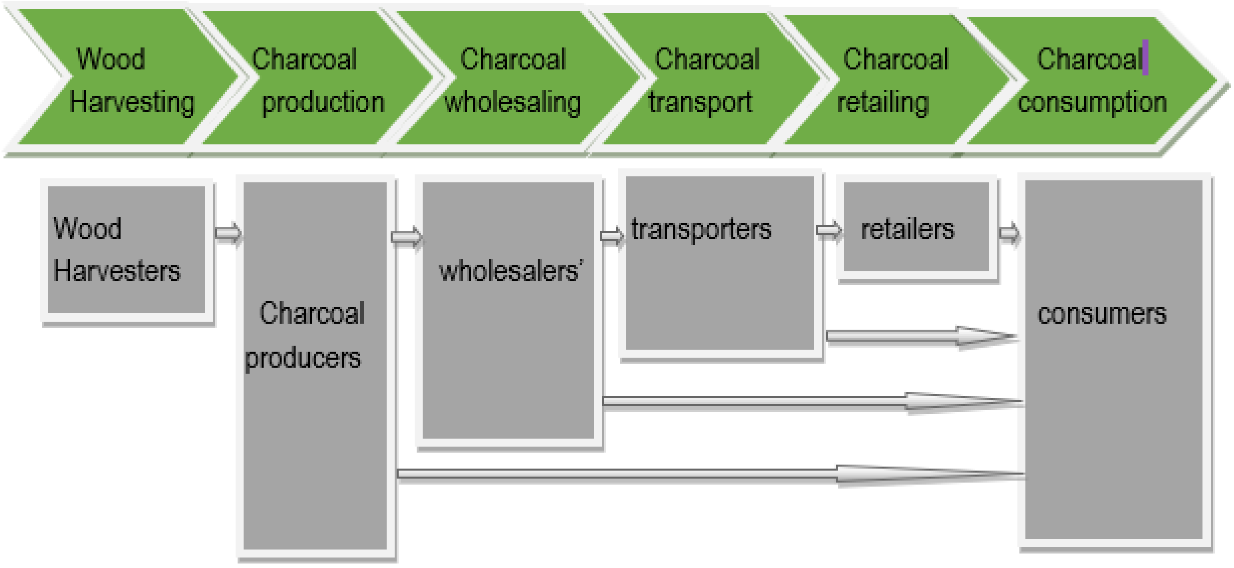
The main actors directly involved along the charcoal marketing chains include producers, distributors/transporters, wholesalers, retailers and consumers (Figure 4.20). The transporters, who come with light trucks, buy up to hundreds of sacks of charcoal to sell to both retailers and directly to consumers. Their main sales are to retailers in major urban areas. Charcoal retailers buy charcoal in a sack from charcoal depots or transporters and sell in small retail shops to low-income consumers who are not able to pay for a sack of charcoal. The price of charcoal is much higher when purchased in small retail shops than in sacks. In some cases, consumers can buy directly from producers or distributors; depot owners are also engaged in retailing charcoal. In addition to the local market, there are reportedly also some illegal exports, mainly to Djibouti, Kuwait, Saudi Arabia, Sudan and Somaliland (Bekele and Girmay 2013).

As the charcoal commodity is moved from the point of production through markets to consumers, it incurs various costs: production, transport and other informal costs (e.g., bribes and payments to brokers, loading–unloading, and, in a few cases, payment by producers to those who claim to have ownership rights over the trees). Thus, it is problematic to accurately present the cost-benefit distribution of the business along its chain. According to the recent national charcoal value chain assessment, most of the charcoal produced in Ethiopia is traded and supplied to consumers through the following channels:

- Channel 1: Illegal private producers – private vendors – urban consumers
- Channel 2: Illegal private producers – foreign smugglers – foreign market
- Channel 3: Licensed and permitted private/group producers – private vendors – urban consumers
- Channel 4: Illegal regular household level producers – local vendors – local consumers
- Channel 5: Illegal irregular producers directly to roadside buyers or local consumers

Of these, Channel 4 – the illegal regular household level charcoal producer to local towns – is the most frequent charcoal production-supply channel covering much of the charcoal-producing regions in Ethiopia, mainly with pastoral/agro-pastoral and mixed farming communities in the dry lowlands (Ministry of Environment Forest and Climate Change 2016). The distribution of income and profit sharing in the illegal charcoal production-supply channel in Ethiopia is highly skewed towards the producers, who are earning around 75 per cent (225 birr) of the total revenue per bag (Ministry of Environment, Forest and Climate Change 2016).

Figure 4.20. Map of charcoal supply chain



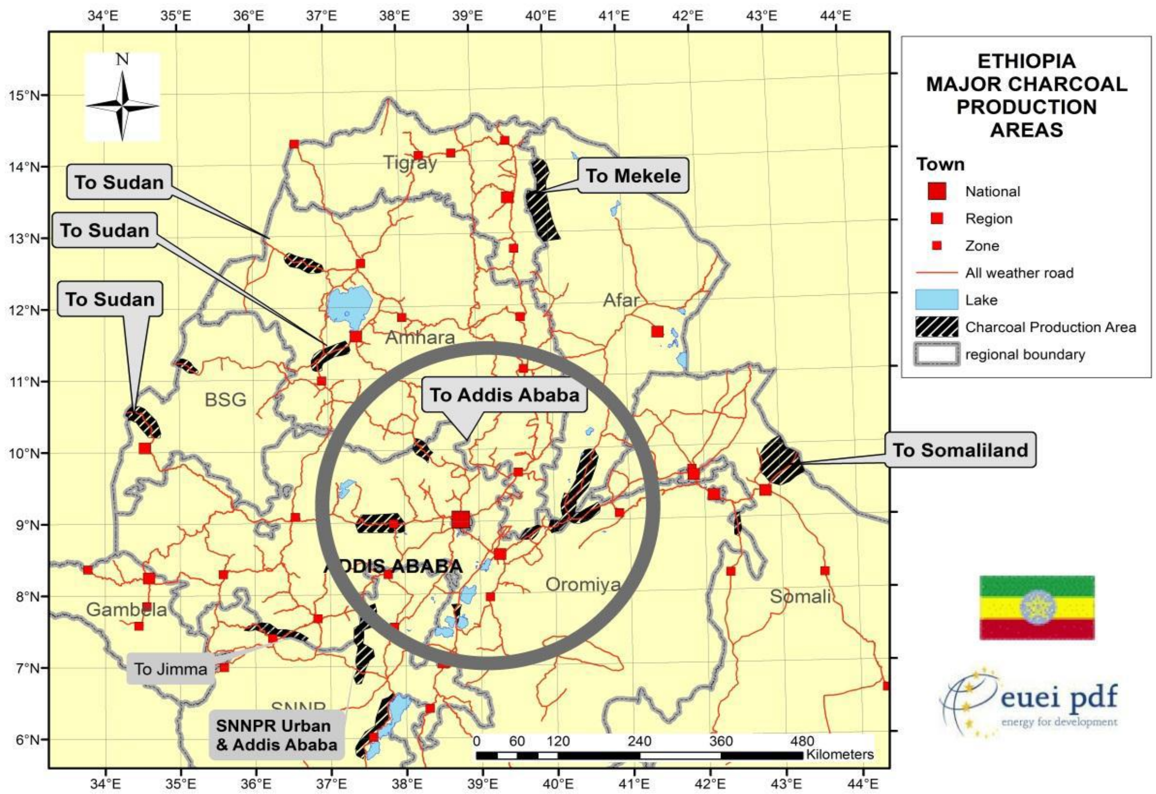
Source: Designed by authors using data from Bekele and Girmay 2013.

Figure 4.21. Charcoal depots

Source: Bekele and Girmay 2013.

Location of the activity
Most charcoal coming to towns and cities is produced, transported and retailed illegally. It is transported to urban centres using trucks, automobiles, camels and donkeys. A charcoal inflow survey conducted in August 2012 into the city of Addis Ababa alone showed an average of over 42,000 sacks of charcoal coming to the city each day (Bekele and Girmay 2013). The acacia-dominated dry woodland and shrubland areas, which cover over 60 per cent of the total landmass of Ethiopia, constitute the largest source of wood for the bulk of charcoal coming to urban centres in the country (Food and Agriculture Organization 2017). The bulk of charcoal comes from either acacia species and/or the invasive species *Prosopis juliflora* through the eastern gate to Addis Ababa. Gewane in Afar, Bilate in SNNPR, Langano and Borana in Oromiya, and Harshin in the Somali regions are some of the major charcoal suppliers to towns and cities in each region (Map 4.18).

Map 4.18. Main locations of charcoal production



Source: Geissler *et al.* 2013.

4.11.5 Conclusions and recommendations

BIOGAS

Synthesis of the findings
It is estimated that the income of some masons more than doubled thanks to the biogas programme. The wages of the masons vary by region. In Tigray and Amhara, masons are only paid from the subsidy by the government. In Oromia and SNNPR, the biogas owners pay an additional amount of 1,114-1,739 birr to masons, depending on the volume of the plant, as contract bases.

The income of households was measured based on cost savings such as savings on wood fuel, charcoal, dung cake, kerosene and chemical fertilizer per year. Only a small number of households sell the bioslurry. The biggest savings are associated with the purchase of firewood, followed by fertilizer.

Given the high potential for domestic biogas plants – from 1.1 million to 3.5 million households in the four regional states studied here (Eshete, Sonder and ter Heegde 2006) – the potential to promote better wages and savings at a household level is high.

Practices and policies to improve sustainability

Better training of the masons and better information for the households with a biodigester will contribute to increasing the wages and savings associated with biodigesters. If households understand well the economic benefits of the biodigesters, they will better maintain them and this will result in better and longer use of the biodigesters.

Future monitoring

Monitoring the wages paid in the biogas sector and the savings at the household level would be extremely useful to reinforce the development of the biogas programme and promote the development of biodigesters.

CHARCOAL

Synthesis of the findings

Charcoal is a major income source for poor households in rural areas and is the primary source of fuel in most urban areas of Ethiopia. Charcoal incurs various costs like production, transport, taxation, bribes and payments to brokers, loading–unloading, and, in a few cases, payment for ownership rights, etc. when it moves from the point of production through markets to consumers. Thus, it is difficult to accurately present the cost-benefit distribution of the business along its chain. Distribution of income and profit sharing in the charcoal production-supply channel in Ethiopia is highly skewed toward the producer (75 per cent of the total revenue/bag, which is 225 birr).

Charcoal turns out to be among the most important and reliable cash income sources compared to incomes from semi-subsistence crop and livestock activities, which are subject to climatic and other calamities.

Practices and policies to improve sustainability

Charcoal is particularly important as a means of generating income for some of the poorest members of society. It also saves foreign exchange that would otherwise be used to import fuel. A large number of people are employed in the various phases of the charcoal value chain, including: collection and sizing of wood; preparation of charcoal kilns; loading the wood into kilns and unloading charcoal after conversion; unloading, bundling, packaging and transport; and marketing. Additional indirect employment is generated by the activities that use charcoal.

Because millions of people depend on charcoal as a source of energy and income, and charcoal is also the cause of environmental degradation, an institutional intervention becomes mandatory to promote and regulate more environmentally friendly manners of producing charcoal. To improve the conditions in the charcoal industry, first it would be necessary to set the charcoal issue as an important and urgent policy agenda.

Future monitoring

Monitoring of the wages paid in the charcoal sector and the cost-benefits along the supply chain would be extremely useful to reinforce the development of the charcoal sector.

4.11.6 References

Bekele, M. and Girmay, Z. (2013). *Reading Through the Charcoal Industry in Ethiopia: Production, Marketing, Consumption and Impact.* Forum for Social Studies. Addis Ababa.

Berhe, M., Hoag, D., Tesfay, G. and Keske, C. (2017). Factors influencing the adoption of biogas digesters in rural Ethiopia. Energy, *Sustainability and Society* 7(10), 1-11. http://dx.doi.org/10.1186/s13705-017-0112-5.

Eshete, G., Sonder., K., and ter Heegde, F. (2006). *Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia.*

Food and Agriculture Organization of the United Nations (2017). *The Charcoal Transition: Greening Charcoal Value Chain to Mitigate Climate Change and Improve Local Livelihoods*. Rome.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Haftu, E. and Abel, O. (2016). Biogas as an alternative energy source and a waste management strategy in Northern Ethiopia. *Biofuels* 7(5), 479-487, http://dx.doi.org/10.1080/17597269.2016.1163211.

Mengistu, M., Simane, B., Eshete, G. and Workneh, T. (2016). Institutional factors influencing the dissemination of biogas technology in Ethiopia. *Journal of Human Ecology*, 55(1,2): 117-134. http://dx.doi.org/10.1080/09709274.2016.11907016.

Ministry of Environment, Forest and Climate Change (2016). *The Charcoal Industry Assessment of Ethiopia: Policy and Institutional Restructuring for Sustainable Charcoal.* Supported by Global Green Growth Institute. Addis Ababa.

Mulu, G. (2016). *Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia: The Case of Ofla and Mecha Woredas*. A Thesis Submitted to Center for Environment and Development Studies. Addis Ababa University. Addis Ababa.

Rogers, E.M. (1983). *Diffusion of Innovations*. New York: The Free Press.

SNV Netherlands Development Organisation (2007). *Ethiopia Biogas for Better Life. Brief Programme Profile*. Ethiopia Rural Energy Development and Promotion Centre. Addis Ababa.

Yitayal, A. (2015). Status and benefits of renewable energy technologies in the rural areas of Ethiopia: A case study on improved cooking stoves and biogas technologies. *International Journal of Renewable Energy Development* 4(2), 103-111. http://dx.doi.org/10.14710/ijred.4.2.103-111.

4.12 Indicator 12. Jobs in the bioenergy sector

4.12.1 Researcher(s)

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4.12.2 Description

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 International Labour Organization (ILO) Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors

4.12.3 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

4.12.4 Overall methodology of the implementation

The indicator applies to both the biogas and the solid biomass (fuel wood and charcoal) pathways. Secondary data, literature review and expert assessments were used. This indicator is closely linked to Indicator 21 on training and requalification of the workforce, and to Indicator 13 on the activity of women and children.

The ILO fundamental principles and rights at work declares:

a) Freedom of association and the effective recognition of the right to collective bargaining.
b) The elimination of all forms of forced or compulsory labour.
c) The effective abolition of child labour; and
d) The elimination of discrimination in respect of employment and occupation

Generally, three categories of the total employed are distinguished (United Nations Department of Economic and Social Affairs 2007):

- Wage and salaried workers (also known as employees);
- Self-employed workers that include self-employed workers with employees (employers), self-employed workers without employees (own-account workers) and members of producers' cooperatives; and
- Contributing family workers (also known as unpaid family workers; note this is a sub category of self-employed workers, separated on account of the fact that the socio-economic implications associated with this status can differ significantly from other self-employed workers).

4.12.5 Key findings

BIOGAS

According to the Netherlands Development Organisation ([SNV] 2016), more than 2,000 masons have been trained nationwide in Ethiopia. In addition, masons have used daily labourers during the biogas plant construction period, opening additional short-term employment opportunities in the target localities. Nevertheless, there is a lack of documented evidence to present the exact number of jobs created by the programme. Jobs in management and finance have also been included accordingly.

Explanations of the jobs associated with biogas (Table 4.43) are as follows.

- Total energy produced by the working biodigesters (77 per cent of 22,166 biodigesters) is 388 * 10^6 MJ/yr.
- Total working population is 57,750,000, representing 55 per cent of the total Ethiopian population of 105 million in 2017, as per the latest census figures.
- Due to lack of specific information about the distinction between temporary and indefinite jobs in biogas sector, sub-indicator 12.3 has not been calculated.
- Sub-indicator 12.4 requires the percentage of jobs generated in the biogas sector that adhere to nationally recognized labour standards. These standards should be consistent with the principles enumerated in the ILO Declaration on Fundamental Principles and Rights at Work. Compliance with national labour standards the bioenergy sector has to be placed in perspective with compliance levels in comparable economic sectors (sub-indicator 12.5 in Table 4.44). According to Ethiopian labour code, for any employee in a profession, in his/her religion, gender, race and political views, no discrimination will be made among them; and

rights of all employees are respected and safeguarded. Therefore, it has been considered that the employment generated in the biogas sector complies with the ILO Declaration on Fundamental Principles and Rights at Work.

- The number of net jobs created (2,813) in sub-indicator 12.1 represents the sum of the total number of skilled/trained masons (2,161) and unskilled/daily labourers (652); whereas the number of total jobs (3,171) in sub-indicator 12.4 represents the overall employment generated in the sector, including skilled jobs, unskilled jobs and jobs in management and finance.

Table 4.43. Direct jobs associated with the biogas production value chain, 2015-2018

Sub-Indicator(s)	Measurement scenarios	Unit of measurement	Quantity of jobs	Jobs/MJ	Percentage share (%)
12.1	Net job creation	Number	2 813	$7.25*10^{-6}$	100%
12.2	Skilled jobs	Number	2 161	$5.57*10^{-6}$	76.82%
	Unskilled jobs	Number	652	$1.68*10^{-6}$	23.18%
12.3	Indefinite jobs	Number	NA	NA	NA
	Temporary jobs	Number	NA	NA	NA
12.4	Total jobs	Number	3 171	$8.17*10^{-6}$	-
	Jobs in relation to total working population	%	0.00005491	-	0.005491%
12.5	Jobs in compliance with ILO	%	100%	-	100%

Source: NBPE 2015; NBPE 2018; Zerihun 2015; Rai 2018; Seyoum 2018; SNV 2018.

FUEL WOOD

A number of job opportunities have been created in firewood sectors across the country. The types of jobs included in Table 4.44 are: jobs in fuelwood plantation, harvesting, transport, wholesalers, fuelwood retailing, fuelwood processing and utilization/consumption. Jobs related to management systems and finance are also included.

Moreover, people are organized and employed both formally and informally in business activities related to fuelwood production to consumption. However, there are no specific recorded data on the number of informal jobs in the sectorm and hence informal jobs are not included in the computation of the indicator. More particularly, the commercialization and formalization of wood fuel production and transport/marketing provides the basis for wood energy as a value chain. Naturally, options for the deliberate modernization of wood-energy value chains are most prevalent in and around large centres of consumption (e.g., cities) with easy road access to forest areas. These conditions are not met evenly across Ethiopia. According to interview results, commercialization of wood fuels at present is highest in Tigray, Afar, Amhara and in and around the capital, Addis Ababa.

The fuelwood harvesting process and its utilization as a source of energy is technically unsophisticated. It follows two main alternatives: either (1) self-management by smallholders, or (2) standing stock sales to wholesalers who carry out logging, de-barking and buckling, and stacking for transport on their own charges. The second alternative has been applied by Oromia and Amhara Regional Forest Enterprises, where the standing stock is auctioned off, to be cut and disposed of by the winning applicants.

Some explanation of the jobs associated with the fuelwood value chain (Table 4.44) are as follows:

- Total energy consumed from firewood is $1.87*10^{12}$ MJ.
- Total working population is 57,750,000, representing 55 per cent of the total Ethiopian population of 105 million in 2017.
- The net jobs created (12,800) in sub-indicator 12.1 constitutes the total estimated number of skilled jobs or a well-trained workforce (4,864) and unskilled/daily labourer (7,936) in the fuelwood value chain; whereas, the number of total jobs (13,250) in sub-indicator 12.4 represents the overall employment generated in the sector, including skilled jobs, unskilled jobs and jobs in management and finance.
- Informal jobs are not included in the computation of the indicator.

No detailed information is available on the conformity of the jobs with the ILO principles. As a be reminder, in most areas of Ethiopia, urban households buy fuel wood from traders and retailers; whereas rural households, particularly women and children are forced to travel great distances and spend considerable time to collect fuel wood (see Indicator 13). In that regard, the working conditions are not in compliance with the Ethiopian Labor Proclamation Statement for restricting the job starting age and eliminating forced labour. Therefore, when including the informal jobs in the sector, the ILO Declaration on Fundamental Principles and Rights at work are not met.

Table 4.44. Direct jobs associated with the fuelwood value chain, 2014-2017

Sub-Indicator(s)	Measurement scenarios	Units of measurement	Quantity of jobs	Jobs/MJ	Percentage share (%)
12.1	Net job creation	Number	12 800	$6.84*10^{-9}$	100%
12.2	Skilled jobs	Number	4 864	$2.60*10^{-9}$	38.00%
	Unskilled jobs	Number	7 936	$4.24*10^{-9}$	62.00%
12.3	Indefinite jobs	Number	7 466	$3.99*10^{-9}$	58.33%
	Temporary jobs	Number	5 334	$2.85*10^{-9}$	41.67%
12.4	Total jobs	Number	13 250	$7.09*10^{-9}$	-
	Jobs in relation to total working population	%	0.0002294	-	0.02294 %
12.5	Jobs in compliance with ILO	%	-	-	-

Source: Central Statistical Agency [CSA] 2016; Ethiopia, Ministry of Water, Irrigation and Electricity 2018; SNV 2016; Geissler *et al.* 2013.

CHARCOAL

In the Oromiya and Amhara regions, charcoal was the most widely used form of energy followed by firewood. Marketing of forest products (including charcoal) in most regions of Ethiopia relies on traveling wholesalers who purchase loads of poles and charcoal directly from smallholders (roadside sales).

Charcoal production and marketing has always been almost entirely informally organized and implemented by the private sector. The computed numbers of employment in the sector include jobs in charcoal production transport, retailing and consumption as well as management and finance.

Due to a lack of adequate data, the number of informal jobs in the charcoal value chain were not included in the computation of the indicator. However, charcoal activities along the market chain provide an estimated 380,847 permanent jobs and 905,918 seasonal employment opportunities, amounting to a total of 1,286,765 people employed by the industry (see Indicator 20). The main actors directly involved along the charcoal market chain include tree owner, nursery owner, seed collector, charcoaler, labourer, truck owner, loader, bag producer, wholesaler, stove producer and stove retailer.

Some more explanations of charcoal production value chains are as follow (Table 4.45):

- Total energy consumed from charcoal is $1.66*10^{11}$ MJ.
- Total working population is 57,750,000, representing 55 per cent of the Ethiopian population of 105 million in 2017.
- The net jobs created (8,450) in sub-indicator 12.1 comprises the total number of skilled jobs or a well-trained workforce (2,740) and unskilled/daily labourers (5,710) in the charcoal production and distribution sectors; whereas, the number of total jobs (8,800) in sub-indicator 12.4 represents the overall jobs created in the sector, considering trained/skilled jobs, unskilled jobs, jobs in management and finance.
- Informal jobs are not included in the computation of the indicator.

Table 4.45. Direct jobs associated with the charcoal value chain, 2014-2017

Sub-Indicator(s)	Measurement scenario	Units of measurements	Quantity of jobs	Jobs/MJ	Percentage share (%)
12.1	Net job creation	Number	8 450	$5.09*10^{-8}$	100%
12.2	Skilled jobs	Number	2 740	$1.65*10^{-8}$	32.43%
	Unskilled jobs	Number	5 710	$3.44*10^{-8}$	67.57%
12.3	Indefinite jobs	Number	-	-	-
	Temporary jobs	Number	-	-	-
12.4	Total jobs	Number	8 800	$5.30*10^{-8}$	
	Jobs in relation to total working population	%	0.0001524	-	0.01524%
12.5	Jobs in compliance with ILO	%	-	-	-

Source: CSA 2016; Ministry of Water, Irrigation and Electricity 2018; SNV 2016; Ministry of Environment, Forest and Climate Change 2016; Geissler *et al.* 2013.

4.12.6 Conclusion and recommendations

The conclusions and recommendations for both pathways are integrated.

Synthesis of the findings

The biogas pathway is the source of new activity, particularly for masons, and more than 2,000 masons were trained to build the biodigesters. This may not always correspond to the creation of new jobs, but it reinforces the availability of work for masons. The total number remains very small compared to the total number of jobs in Ethiopia.

The solid biomass sector is the source of a large number of jobs. However, many of these jobs are informal and unskilled, especially in rural areas.

Practices and policies to improve sustainability

The biogas and solid biomass sectors are the source of a large number of formal and informal jobs in Ethiopia. A better knowledge of these jobs is essential to define relevant policies related to sustainable bioenergy production and utilization, to improve the quality of the jobs, and to define the required training activities (see Indicator 21). Recommendations to improve the jobs of the sector include:

- Data regarding informal jobs should be assessed, and these jobs should be recognized institutionally so that they can be converted and organized into formal jobs. Training is extremely important in that sense (Indicator 21). For example, charcoal pricing is subject to individual negotiations, and improving the smallholders' bargaining power would contribute to the formalization of their jobs.

- Women and children contribute greatly to the firewood sector, but their activity does not comply with the basic ILO principles. Recognition of this informal activity would contribute to changing this situation.
- Detailed information by region is needed. Proper organizations should be established at the regional and national levels to collect valid data for proper implementation of the indicator.
- If the production of charcoal were banned, employment in the sector would certainly shift into fuel wood. Therefore, improving and institutionalizing or legalizing the charcoal sector is probably a more sustainable approach, including strong training of charcoal producers (see Indicator 21) and the conversion of informal jobs into formal.

Future monitoring

The development of the bioenergy sector should not only be viewed from the environmental perspective. It also provides economic and social benefits, such as employment. The number of jobs in the bioenergy sector is expected to grow, hence the importance of monitoring employment in the sector, as well as the associated skill and quality level. Specifically, assessment of the informal employment must be reinforced, especially in the solid biomass sector.

For this purpose, an integrated and well-developed data collection process is required, as well as evaluation and handling mechanisms involving regional and national institutions. Currently, there is no central and responsible institution in charge of collecting national statistics on employment in the bioenergy sector in Ethiopia. The assessment of employment in the bioenergy sector can easily be incorporated in one of the national surveys that will be conducted by either the Ministry of Water, Irrigation and Electricity (MoWIE) or the National Biogas Programme of Ethiopia (NBPE). Therefore, it is recommended that various stakeholders such as GIZ, SNV Netherlands Development Organisation, the Ethiopian Environment, Forest and Climate Change Commission, the Ethiopian Ministry of Health and the Ethiopian Ministry of Women and Children Affairs work in collaboration with MoWIE and NBPE to develop a systematic and continual generation of data on employment in the bioenergy sector with its appropriate handling mechanisms.

4.12.7 References

Central Statistical Agency (2016). *Welfare Monitoring Survey.* Addis Ababa.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia.* In cooperation with the Ethiopian Ministry of Water and Energy. Supported by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Ministry of Environment, Forest and Climate Change (2016). *The Charcoal Industry Assessment of Ethiopia: Policy and Institutional Restructuring for Sustainable Charcoal*. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Program, Ethiopia. Volume I: Situation*. Addis Ababa.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey*. Addis Ababa, Ethiopia.

Ministry of Water, Irrigation and Energy (2015). *Report on Biogas Users' Survey.* Addis Ababa.

National Biogas Programme of Ethiopia (2018). *Report of Coordination Units of National Biogas Programme of Ethiopia.* Addis Ababa.

Rai, S. (2018). *National Biogas Programme of Ethiopia (NBPE).* Addis Ababa, Ethiopia.

Seyoum, S. (2018). *The Economics of a Biogas Digester*, Livestock Economics Division ILCA, P.O. Box 5689, Addis Ababa, Ethiopia. https://core.ac.uk/download/pdf/132634928.pdf.

SNV Netherlands Development Organisation (2018). *Report on National Biogas Users' Survey, 2018.* National Biogas Programme of Ethiopia. Addis Ababa.

United Nations Department of Economic and Social Affairs (2007). *Indicators of Sustainable Development: Guidelines and Methodologies*. Third edition. New York.

Zerihun, Y.A. (2015). The benefit of use of biogas energy in rural areas of Ethiopia. *African Journal of Environmental Science and Technology* 9(4), 332-345. doi: 10.5897/AJEST2014.1838.

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

4.13.1 Researcher(s)

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4.13.2 Description

(13.1) 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.

4.13.3 Measurement unit(s)

Hours per week per household/ percentage

4.13.4 Overall methodology of the implementation

Secondary data, based on literature review, were used for the measurement of this indicator. The focus was on the time saved thanks to the replacement of traditional bioenergy (open fires) by modern bioenergy services as selected in the two pathways (solid biomass used in improved cookstoves and biogas).The methodology aims at comparing the time spent for cooking and other household activities before and after the use of the biogas and the improved cookstoves.

4.13.5 Key findings

BUSINESS-AS-USUAL: THE USE OF TRADITIONAL BIOMASS

In Ethiopia, the household sector accounts for 90 per cent of the total energy consumed, and most households (93 per cent) depend on traditional open fires (Manuye *et al.* 2018). Female household members are primarily responsible for fuelwood collection and are the primary cooks in the household: more than 90 per cent of firewood collection is undertaken by women (ages 18-59) assisted by female children ages 6 to 17 years old; male children of these same ages are also involved in fuelwood collection (Gwavuya *et al.* 2012).

These tasks have been identified as unpaid work that is time demanding and crucial for the survival of household members (Ferrant, Pesando, and Nowacka 2014). Since biomass resources have been depleted over time, rural women are obliged to travel long distances per day to the forest and to carry heavy loads of fuelwood on their backs, which is an exhausting as well as physically challenging task (Amigun *et al.* 2012).

According to the World Bank (2014) as cited in Rebeca (2017), women and girls spend two hours per day collecting fuel wood on average at the global level. This can reach six hours in some countries, depending on the availability of wood fuel, the deforestation rate, the trend of fuelwood plantation in the area, management practices and the level of awareness of the community.

In Ethiopia, nationwide, 53.3 per cent of households spend more than 7 hours a week acquiring fuel for cooking and more than 15 minutes preparing the stove for each meal (Padam *et al.* 2018).

BIOGAS

Time savings

Some scholars in Ethiopia have studied the role and burden of rural women in collecting fuelwood and the issue of time saved by women and children collecting biomass, cooking and cleaning cooking utensils due to switching from traditional biomass use to biogas. Although the result varies among scholars, the general findings show the importance of modern energy for saving time and reducing the workload of women and children. Some of the findings are as follows:

- The majority of women are highly interested in and satisfied with the cooking aspect of biogas, since biogas technology is simple, easier, quicker, cheap and locally acceptable. In addition, the technology is easy to set up, use and manage (Taleshani and Kia 2001).

- Using a biogas plant has the potential to substitute 2,208 kg and 3,319 kg of fuelwood per year for the 4 m^3 and 6 m^3 biodigesters respectively (Gwavuya *et al.* 2012). Similarly, 6,015 kg and 902 kg of dung cakes per year can be replaced by the 4 m^3 and the 6 m^3 biodigesters respectively.

- According to Getachew (2016), thanks to the use of biogas technology, average times taken for collecting biomass, cooking food, cleaning utensils were reduced by 0.6 hours, 12.8 hours and 3.1 hours per week respectively. According to Eshete, Sonder and ter Heegde (2006), utilization of biogas decreases household workload by two to three hours per day on average.

- Furthermore, the case studies done by Amare (2015) in Fogera district, in Amhara regional state, revealed that since biogas is a quicker and clean cooking fuel, it creates an opportunity for each household to save 185 minutes per day in the time used for collecting fuel wood and cow dung (51 and 38 minutes), cooking (77 minutes) and cleaning utensils (19 minutes), in addition to decreasing the health impacts and physical stress associated with fuelwood collection. This is close to the findings of Rana, Thapa and Subedi (2015) that on average households using biogas save 96 minutes per day for cooking as compared to traditional biomass users.

- The variation in time saved may relate to differences in the type and amounts of food and in the means of preparation. For instance, in Ethiopia, cooking “Doro wete” takes longer than cooking other foodstuff. Similarly, the time taken for cleaning cooking utensils is determined by the type of food, cleaning material, amount of the soot covering the pots and time needed for cooking. That is why the time saved per day for cleaning cooking utensils – at 19 minutes – is far different from the findings of Renwick, Subedi and Hutton (2007), which was 39 minutes per day.

Table 4.46. Average time saved before and after the adoption of biogas technology.

	Amare (2015)			Getachew (2016)	Eshete *et al.* (2006)
Activities	**Average time needed in minute /day**		**Average time saved minute/day**	**Average time saved minute /day**	**Average time saved per day due to biogas**
	Before	**After**			
Fuel wood collection	76	25	+51	5	-
Cooking	240	164	+77	108	-
Cow dung collection	57	19	+38		-
Cleaning cooking utensil	54	35	+19	26	-
Total	428	243	+185	+139	+120 to 180

Source: Amare 2015; Eshete *et al*. 2016; Getachew 2016.

Although the technology has a great impact on workload reduction, implementing biogas also incurs extra duties both for women and men in households. The use of biogas increased women's average time spent collecting dung, fetching water and feeding the biogas digester:

- The utilization of biogas technology increased women's average time spent fetching water by 26 minutes per day (Amare 2015; Getachew 2016).

- Mixing dung and water adds an extra 15 minutes per day for women (Amare 2015). In addition to other household activities, biogas adopters use an extra five minutes per day for collecting dung, feeding the digester and making dung cake compared with non-users (Getachew 2016).

Gender, violence and socioeconomic activities

Introduction of biogas technology reduces gender inequalities because both men and women participate in biogas adoption training. Because men's average time spent for feeding the biogas digester and mixing water and dung increased, men contributed to women's workload reduction. In addition, since biogas stoves are easier to use, male sons have also become more involved in cooking their breakfasts, feeding the biogas digester and collecting dung (Getachew 2016).

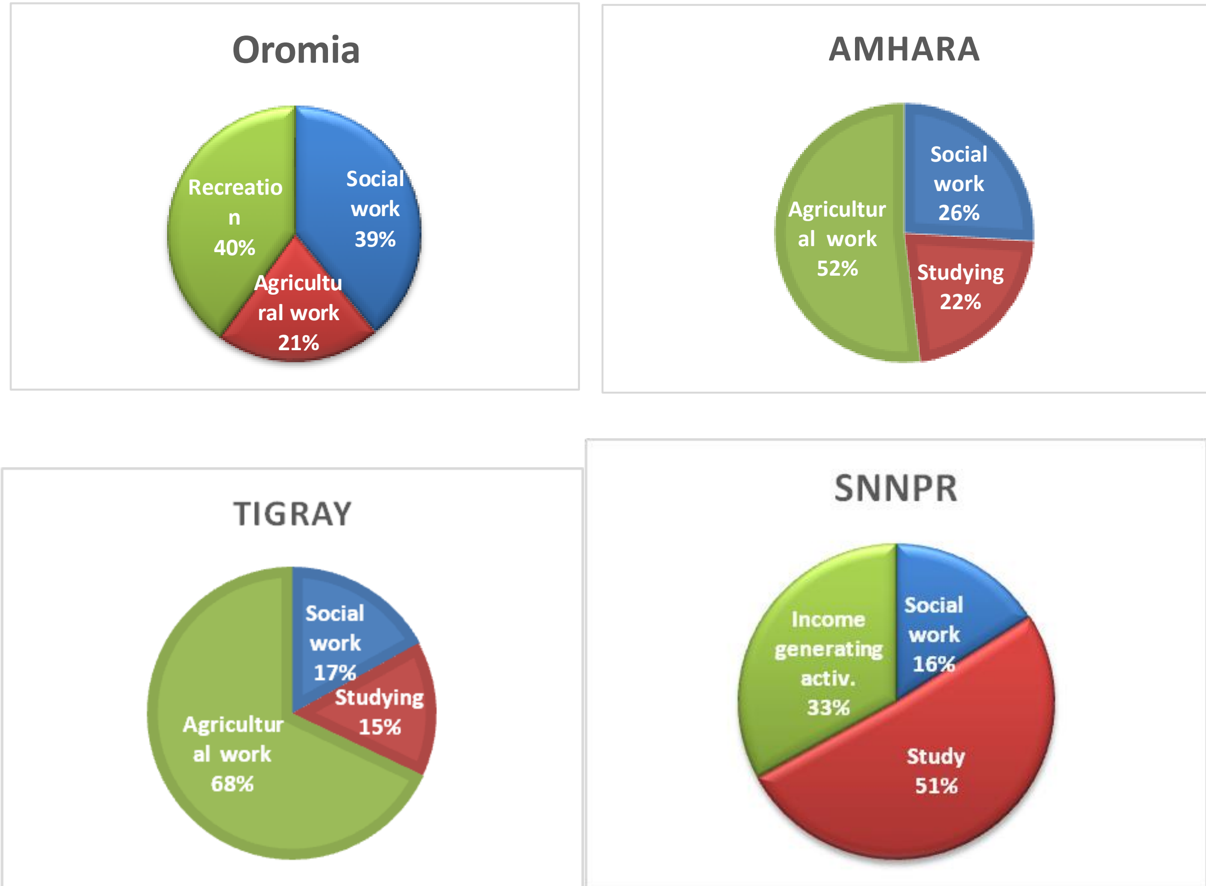
Women have also suffered from risks related to fuelwood collection, such as gender-based violence, wildlife attack and confine by guards as well as associated physical stresses. This is confirmed by the national biogas users' survey (2018), in which surveyed households in the four regional states of Amhara, Oromia, Tigray and SNNPR identified the negative impacts of fuelwood collection as being the extra work burden of biomass collection (74 per cent), violence against women and girls (26 per cent) and children's delay from school (24 per cent). Interestingly, after the adoption of biogas in the study area, more than 90 per cent of the surveyed biogas users confirmed that violence against women and girls had decreased.

Biogas technology has contributed greatly to improving women participation in socioeconomic activities. The time savings from biogas adoption allows women to participate in agricultural production, income-generating activities and other community development projects that help them to improve the social and economic status of the community. In the survey results, 77 per cent of biogas users agreed on the positive impact of biogas for women's participation and empowerment in the study area (Amhara, Oromia, SNNPR and Tigray).

Similarly, based on the results in the biogas user's survey report (2015), the use of biogas creates opportunities for women and girls to be involved in other productive activities (Figure 4.22). Women's use of time varies by region and is affected by a variety of factors such as culture, socioeconomic status, number of family members, and exposure to and availability of different community development projects. Most of the surveyed households in Amhara and Tigray regional states spend their saved time for agricultural purposes, which would contribute greatly to increasing income and food security as a whole. Overall, women and girls are not only affected by the burden of energy poverty, but they also benefit the most compared to other family members when modern energy access is in place (Rewald 2017).

Interestingly, since children were also highly occupied with fuelwood collection, biogas adoption created an opportunity for allocating extra time saved for education, playing longer and washing clothes, which was not in place before biogas adoption. Therefore, the installation of biogas empowers women and promotes girls' education, narrowing the gap in educational status between male and female children (Arthur, Baidoo and Antwi 2011).

Figure 4.22. The allocation of the time saved in each regional state of Ethiopia



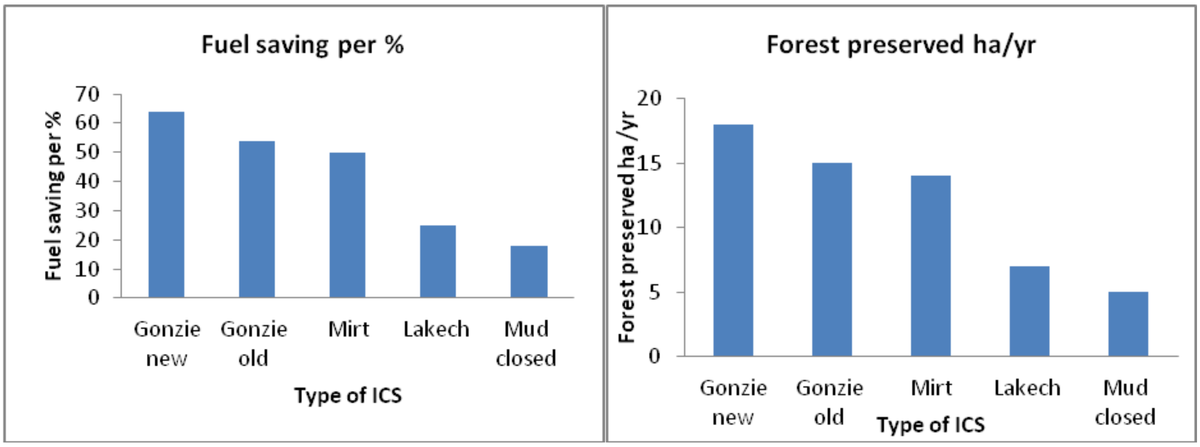
Source: Biogas Users' Survey 2015.

FIREWOOD

Reducing the amount of fuel wood used for cooking is a key driver for the promotion of improved cookstoves in Ethiopia. In addition to reducing the pressure on forestry, it reduces women's workload for cooking (Mamuye Lemma and Woldeamanuel 2018).

The Government of Ethiopia, together with non-governmental organizations, disseminate different types of improved cookstoves. These cookstove differ in their fuel-saving efficiency and therefore in the amount of time saved and forest preserved, as assessed by Alemayehu (2015) (Figure 4.23).

Figure 4.23. Benefits of improved cookstoves



Source: Alemayehu 2015.

4.13.6 Conclusions and recommendations

Conclusions and recommendations for both pathways are integrated.

Synthesis of the findings

In Ethiopia, 95 per cent of the population relies on traditional biomass (open fires) for the source of energy. An estimated 53.3 per cent of households spend more than 7 hours a week acquiring fuel for cooking and more than 15 minutes preparing the stove for each meal. Over 90 per cent of firewood collection is undertaken by women and children. Therefore, the use of biogas and improved cookstoves has the potential to reduce the high demand for wood fuel and therefore the associated workload and time needed for biomass collection and cooking. The time saved can be used for income-generating activities and for improving the social status of the household in the community.

Detailed studies are available regarding the time savings associated with the use of biogas for cooking (up to four hours per day); however, studies related to the time savings associated with improved cookstoves are less precise. Other benefits relate to gender-based violence and the role of women in socioeconomic activities. In other words, switching from traditional use of biomass to biogas and improved cookstoves benefits women and children and the community as a whole.

Polices to improve sustainability

The environmental, economic and social benefits of biodigesters and improved cookstoves are numerous. It is essential to enhance their promotion with strong policies and strategies, as described in the conclusion of this report. The time and workload saved thanks to modern cooking solutions must be well emphasized and integrated in the strategies, so that women and men better acknowledge this benefit. This would reinforce the sustainability of the adoption of biodigesters and improved cookstoves.

Future monitoring of indicator

Alternative solutions for cooking such as biogas and improved cookstoves contribute greatly to saving time and relieving local pressure on wood resources, in line with minimizing the health and environmental impact. However, the change in time spent collecting traditional biomass and cooking with open fires compared to modern cooking solutions is not systematically studied, or studies are limited in magnitude. This results in heterogeneous outcomes. More systematic studies, in different regions and at different moments of time, are needed to gather primary data and better understand the dynamics of cooking with different solutions and the associated time, workload and benefits.

Collaboration with universities and researchers is important for this purpose. This will also contribute to understanding the dynamics of fuel and stove stacking.

4.13.7 References

Alemayehu, Y. A. (2015). Status and benefits of renewable energy technologies in the rural areas of Ethiopia: A case study on improved cooking stoves and biogas Technologies. *International Journal of Renewable Energy Development* 4(2), 103-111.

Amare, Z.Y. (2015). The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District. *African Journal of Environmental Science and Technology* 9(4), 332-345.

Amigun, B., Parawira, W., Musango, J. K., Aboyade, A. O., and Badmos, A. S. (2012). *An Aerobic Biogas Generation for Rural Area Energy Provision in Africa*. http://cdn.intechopen.com/pdfs/31319.pdf.

Arthur, R., Baidoo, M. F. and Antwi, E. (2011). *Biogas as a Potential Renewable Energy Source: Ghanaian Case Study.*

Eshete, G., Sonder, K. and ter Heegde, F. (2006). *Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia*. SNV Netherlands Development Organisation. Addis Ababa.

Ferrant, G., Pesando, L.M. and Nowacka, K. (2014). *Unpaid Care Work: The Missing Link in the Analysis of Gender Gaps in Labour Outcomes.* Issues paper. https://www.oecd.org/dev/development-gender/Unpaid_care_work.pdf.

Getachew, M. (2016). *Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia: The Case of Ofla and MechaWoredas*. Ph.D Thesis. Addis Ababa University.

Gwavuya, S. G., Abele, S., Barfuss, I., Zeller, M. and Müller, J. (2012). Household energy economics in rural Ethiopia: A cost-benefit analysis of biogas energy. *Renewable Energy* 48, 202-209.

Jacob, N. (2013). Promotion and use of improved cookstoves in the conservation of biomass resources and biomass briquettes from solid wastes in the Gambia. *ISESCO Journal of Science and Technology* 9(1), 17-26

Mamuye, F., Lemma, B., and Woldeamanuel, T. (2018). Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia. *Sustainable Environment Research* 28(1), 32-38.

Padam, G., Rysankova, D., Portale, E., Bonsuk Koo, B., Keller, S. and Fleurantin, G. (2018). *Ethiopia. Beyond Connections: Energy Access Diagnostic Report Based on the Multi-Tier Framework.* World Bank. Washington, D.C. https://www.esmap.org/node/170494.

Rana, S.A., Thapa, S. and Subedi, N. (2015). *Impact of Biogas on Reducing Pressure on Forests and Workload of Women in Terai Arc Landscape (TAL), Nepal.*

Renwick, M., Subedi, P.S. and Hutton, G. (2007). *A Cost-benefit Analysis of National and Regional Integrated Biogas and Sanitation Programs in Sub-Saharan Africa*. http://www.susana.org/docs. Accessed 20 April 2019.

Rewald, R. (2017). *Energy and Women and Girls: Analyzing the Needs, Uses and Impacts of Energy on Women and Girls in the Developing World.* Oxfam Research Backgrounder Series.

SNV Netherlands Development Organisation (2015). *Report on National Biogas Users' Survey*. National Biogas Programme of Ethiopia. Addis Ababa.

SNV Netherlands Development Organisation (2018). *Report on National Biogas Users' Survey, 2018.* National Biogas Programme of Ethiopia. Addis Ababa.

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

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4.14.1 Description

(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

Secondary data, retrieved from official reports and literatures, were used. Where possible, the different components of the access to modern energy services (electricity, cooking, mechanical power for productive use) should be separated in the calculation. Since the two pathways selected for Ethiopia are focused on energy for cooking, the indicator is calculated for the access to modern cooking services.

The GBEP definition of modern energy services for cooking is based on two criteria: energy efficiency and safety to human health. Where modern energy services rely on the combustion of fuels, the fuels (whether solid, liquid or gaseous) must be burned in efficient and safe combustion chambers, improved cookstoves, or fuel cells. Improved cookstoves comprise closed stoves with chimneys, as well as open stoves or fires with chimneys or hoods, but exclude open stoves or fires with no chimney or hood. Improved cookstoves usually have energy efficiency higher than 20-30 per cent, and their flue gases are released distant from their users.

4.14.4 Key findings

SUB-INDICATOR 14.1A

Total final energy consumption in Ethiopia was 42.15 Mtoe in 2016 (International Energy Agency [IEA] 2018). Ninety per cent of the final energy was consumed by households. Fuels from solid biomass (fuelwood, charcoal, animal dung and crop residues) are the main energy sources for cooking. But most of them are used in a traditional way as three-stone open fires and cannot be considered as modern energy end-use. The question is therefore to assess the amount of fuelwood used for cooking that can be considered as providing modern bioenergy services.

Improved biomass cookstoves

According to the Ministry of Environment, Forest and Climate Change ([MEFCC] 2018), total consumption of biomass reached 100 million tons in 2013 (roundwood, branches, leaves, charcoal as wood), and 140 million tons if residues and dung are added. Gaia (2014) reported the number of households in Ethiopia to be 18,627,682 (77 per cent rural and 23 per cent urban). The author also indicated that households used more than 122 million tons of biomass, which is the same order of magnitude as MEFCC (2018). This results in an average of more than 5,000 kg biomass fuel per household per year (more than 7,000 kg if residues and dung are included).

On the other hand, a total of 9 million improved cookstoves were distributed to households during GTP I (2011-2015) (Netherlands Development Organisation [SNV] 2018). It is also estimated that 11 million improved cookstoves were distributed in Ethiopia by 2017. MIRT and Gonzie (for injera baking) and Tikikil and Lakech (for non-baking services) were the most common stoves. Their thermal efficiencies were 15 per cent, 15 per cent, 28 per cent and 38 per cent, respectively (SNV 2018) and they had an average thermal efficiency of 24 per cent. According to the recommendations of the Clean Cooking Alliance, only the Tikikil and Lakech stoves are considered sufficiently efficient (more than 25 per cent) to be considered improved cookstoves. Tikikil and Lakech stoves are still used by a limited part of the population.

In summary, only around an estimated 10 per cent of households use efficient stoves (for baking), and penetration of other modern and clean cookstoves is well below 10 per cent (SNV 2018). According to Sustainability for All statistics, only 3.5 per cent of the population has access to clean fuels and technologies for cooking ([SEforALL] 2018).

For this study, we assume an optimistic value of 10 per cent of households using improved biomass cookstoves considered as modern cooking solutions. An average energy efficiency of 28 per cent is considered for the improved biomass cookstoves, which is a little bit optimistic, and 8 per cent for the other stoves. Considering a total biomass consumption of 122 Mtons of fuelwood, a total of 3.75 Mtons/yr of fuelwood (1299 ktoe/yr) is consumed by the households with improved cookstoves, and 118 Mtons/yr by the households without improved cookstoves (Table 4.47). This corresponds to modern energy services of 364 ktoe/yr, taking into consideration the efficiency of the stoves.

Table 4.47. Computation of Indicator 14 for solid biomass

1 PJ = 23.88 ktoe
1 GJ = 0.00002388 Ktoe

	Households with modern biomass cooking solutions	**Households without modern biomass cooking solutions**
Mton biomass	122	
Total households	18.6	
Share	10%	90%
million households	1.86	16.74
efficiency of the stove	28%	8%
ton biomass/household/yr	2.02	7.06
ktoe biomass/household/yr(1)	0.000699	0.00245
Mton biomass/yr	3.75	118.25
ktoe biomass/yr(1)	1 299.81	40 943.91
ktoe energy service/yr(1)	**363.95**	**3 275.51**
ktoe energy services/household/yr(2)	**0.000242**	**0.000242**

(1) Assumption: 14.5 MJ/kg wood
(2) Heat available for cooking (produced by the stove)

Biogas
From the total of 22,166 biodigesters already distributed in the country (Rai 2018), only 77 per cent are functional and hence, 17,068 households are utilizing biogas as modern energy. Each biodigester produces an estimated 2.83 m^3 of biogas per day (Indicator 17), and the efficiency of the biogas stove is 57 per cent. This results in a final energy consumption of 9.3 ktoe/yr, equivalent to energy services of 5.3 ktoe/yr.

Table 4.48. Computation of Indicator 14 for biogas

	Households with biogas cooking solutions
million households with functional biodigester	0.017
efficiency of the stove	57%
m^3 biogas per household	2.8
m^3 biogas/household/yr	1 033.0
ktoe biogas/household/yr (1)	0.0005427
million m^3 biogas/yr	17.6
ktoe biogas/yr (1)	9.3
ktoe energy service/yr (2)	5.28
ktoe energy services/household/yr (2)	0.0003093

(1) Assumption: 22 MJ/m^3 biogas
(2) Heat available for cooking (produced by the stove)

Electricity
The main energy resource used in electricity generation is hydropower. The electricity power system of Ethiopia consumes 832 ktoe of hydropower (Yurnaidi and Kim 2018). According to these authors, 38.7 per cent of electricity is consumed in the residential sector (35.8 per cent for lighting and 1.32 per cent for cooking services). Hence, 11 ktoe of hydropower electricity is used for household cooking services in the country.

Fossil-fuel services
According to SNV (2018) of the 36.4 Mtoe generated in Ethiopia in 2014, 8 per cent is for petroleum. Yurnaidi and Kim (2018) showed further that 1.43 per cent of energy from fossil fuel goes for residential cooking service. Hence, only about 41.6 ktoe used for cooking services is from fossil fuel.

Synthesis
The access to modern cooking energy services is estimated at:

- 364 ktoe for improved biomass cookstoves
- ktoe for biodigesters
- 11 ktoe for electricity services
- 42 ktoe for fossil fuel services
- Total: 1,168 ktoe

Cooking services with traditional cooking solutions represent 4,044 ktoe.

SUB-INDICATOR 14.1B

Improved biomass cookstoves
Around 11 million cookstoves had been distributed by 2017. However, as discussed above, many of them cannot be considered as improved cookstoves given their low efficiency. Based on SNV (2018), we assume that 10 per cent of households use improved biomass cookstoves considered as modern cooking solutions according to the usual definitions.

Biodigesters
From the total of 22,166 biodigesters already distributed in the country (Rai 2018), only 77 per cent are functional, and hence 17,068 households utilize biogas as modern energy. This represents less than 0.1 per cent of total households.

Electricity services
It has been reported that 42.9 per cent of the Ethiopian population had access to electricity, broken down into 85.4 per cent of the urban population and 26.5 per cent of the rural population. Assuming that the same rate applies to households (this assumption neglects the different sizes of households in urban and rural areas), the number of households with electricity is 8 million, or 3.3 urban households and 3.9 rural households. Moreover, it is estimated that 4.1 per cent of households cook with electricity (Padam *et al*. 2018). This low value is surprising given the low cost of electricity. The low reliability of the grid, upfront costs of electric stoves and cultural factors are possible reasons below these low values.

Synthesis
In total, 1.9 million households have access to modern cooking services and 8 million households have access to electricity services. Ethiopian households with access to modern energy could be estimated by summing households with access to bioenergy and electricity, but this needs to consider that some households have access to both. Due to the lack of data, we considered that half of the households with access to modern cooking services also have access to electricity services, i.e., 0.95 million households. This results in 8.9 million households with access to modern energy services (0.95 million only modern cooking + 7.05 million only electricity + 0.95 million both).

It is interesting to note that the total number of households with modern cooking services is less than the urban households with electricity access, which proves that many urban households still do not have access to modern cooking services.

The percentage of households with access to modern energy through bioenergy is calculated using the following formula and result obtained is 21 per cent (1.9/8.9).

$$\% = \frac{\text{No. HH with access to modern energy from modern bioenergy}}{\text{No of HH with access to modern bioenergy}} 100$$

SUB-INDICATOR 14.2

Based on the data provided for sub-indicator 14.1, the total number of households using bioenergy is:

- Modern bioenergy services: 1.9 million (10 per cent)
- Traditional bioenergy services: 16.7 million (90 per cent)
- Total: 18.6 million

4.14.5 Conclusions and recommendations

Synthesis of the findings
Only 10 per cent of households are estimated to have access to modern bioenergy services, mostly through improved cookstoves. Around 43 per cent of households have access to electricity, and 4 per cent of households cook with electricity. Less than 0.1 per cent of households have a biodigester.

Policies to improve sustainability
Further expansion of biodigesters could help rural people in particular to gain access to modern energy services. Many people have already gained exposure to the benefits that could be obtained

by having biodigesters. The cattle population in Ethiopia is also very high and provides dung as a feedstock for anaerobic digestion. For biogas to enhance access to modern energy services, support is required from government policies, such as the National Energy Policy. This would facilitate the development of the biogas market and the application of advanced technologies so that biogas can be used in an efficient and safe way. There are also alternative feedstocks for biogas production in the country, such as agricultural residues, coffee husks, water hyacinth and fruit processing wastes. As a result, bioenergy development and utilization in the country has a bright future.

The share of households using improved cookstoves is also found to be progressing. The promotion of more-efficient and cleaner stoves, such as pellet stoves, should be explored. Other interesting stoves are the thermo-electric generation stoves, providing electricity capacity to charge a phone or a solar lamp – for example, ACE1 stoves (https://africancleanenergy.com/), or Biolite stoves (http://catalog.cleancookstoves.org/stoves/64), where excess heat is converted to electricity.

With increasing household incomes, there will be a need for cleaner and more convenient energy sources, such as LPG and electricity, instead of traditional energy sources. It is necessary to conduct deeper studies to understand the problems associated with promoting bioenergy and how to simplify bioenergy production in the country. This needs close follow-up by the responsible persons. Appropriate energy policies should also be in place to facilitate efficient use of bioenergy. There is also a need for strong coordination and cooperation among local and international institutions in order to carry out these studies successfully.

Future monitoring

Future monitoring of bioenergy utilization in Ethiopia should focus on overcoming data gaps and making available updated data. Institutional relationships also should be smoothed out and organized.

The specific energy needs for injera baking stoves deserve more analysis. Injera stoves consume a significant amount of cooking energy per household, but specific data on those stoves are not available. The analysis of fuel and stove stacking (several fuels and stoves used for cooking) also deserves deeper analysis in order to understand how to reduce the parallel use of clean and unclean cooking solutions.

Finally, the new multi-tiered approach proposed by the World Bank to measure energy access is of high interest for a detailed monitoring of energy access (Padam *et al*. 2018. It reports the access to modern energy cooking solutions according to six attributes (efficiency, exposure to pollution, convenience to gather and prepare the fuel and stove, safety, affordability and fuel availability).

4.14.6 References

Gaia Association (2014). *Holistic Feasibility Study of a National Scale-Up Program for Ethanol Cookstoves and Ethanol Micro Distilleries in Ethiopia. Assessment of Cooking Energy in Households, Commercial Enterprises and Social Institutions in Ethiopia.* Addis Ababa.

International Energy Agency (2018). Total primary energy supply of Ethiopia in 2018.

Ministry of Environment, Forest and Climate Change (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia, Strengthening the Enabling Environment for Clean Cooking Project*. Final report. Addis Ababa.

Padam, G., Rysankova, D., Portale, E., Koo, B.B., Keller, S. and Fleurantin, G. (2018). *Ethiopia, Beyond Connections, Energy Access Diagnostic Report Based on the Multi-Tier Framework,* World Bank. Washington, D.C. http://documents.worldbank.org/curated/en/372371533064359909/pdf/Ethiopia-Beyond-connections-energy-access-diagnostic-report-based-on-the-multi-tier-framework.pdf.

SNV Netherlands Development Organisation (2018). *Review of policies and strategies related to the clean cooking sector in Ethiopia, strengthening the enabling environment for clean cooking project*, Final Report. Addis Ababa.

Sustainable Energy for All (2018). Country statistics of Ethiopia. https://www.se4all-africa.org/seforall-in-africa/country-data/ethiopia/.

Yurnaidi, S. and Kim, S. (2018). Reducing biomass utilization in the Ethiopia energy system: A national modeling analysis. *Energies* 11, 1745; doi:10.3390/en11071745.

4.15 Indicator 15. Change in mortality and burden of disease attributable to indoor smoke

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4.15.2 Description

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

4.15.3 Measurement unit(s)

Percentages

4.15.4 Overall methodology of the implementation

A review of available studies in Ethiopia was conducted to better understand the effects of smoke on health as well as the role of biogas on health improvement. Data on household air pollution related to biogas and solid fuel from Ministry of Water, Irrigation and Energy (MoWIE), and Netherlands Development Organisation (SNV-Ethiopia) reports were particularly useful. Data from the World Health Organization and regional studies were also used. These data mainly emphasize the benefits of the biodigesters and miss data associated with improved cookstoves.

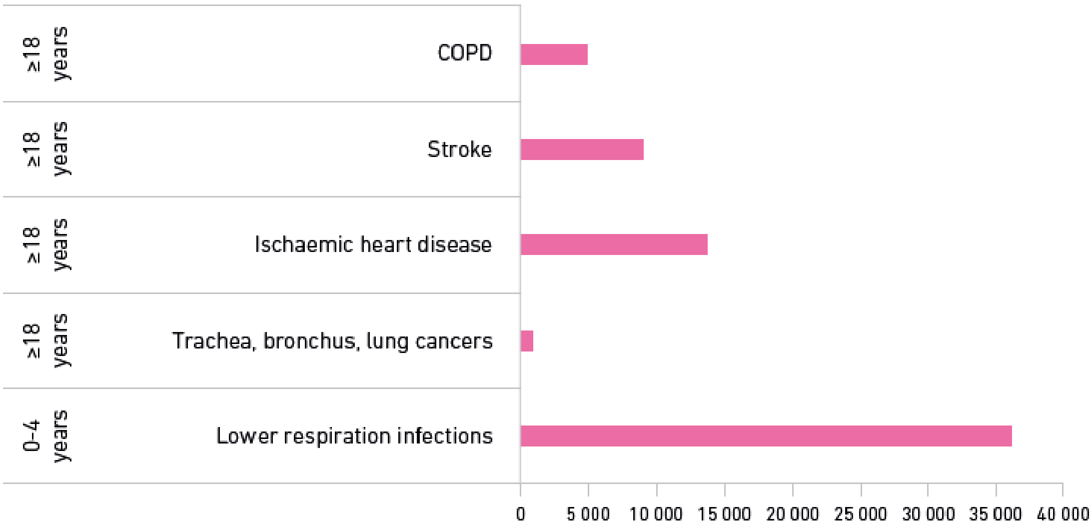
4.15.5 Key findings

THE CURRENT SITUATION

According to the report of the Ministry of Health, 1,262,908 (5 per cent) cases of acute upper respiratory infections and pneumonia in 2010/11 may have been linked to household and outdoor air pollution. Due to high concentration of household air pollution in Ethiopia, the national estimates of the burden of diseases such as acute lower respiratory infection and chronic obstructive pulmonary diseases is high (Institute for Health Metrics and Evaluation 2014).

A recent World Health Organization report states that air pollution (household and outdoor) is the single largest environmental risk factor for premature death in Ethiopia, and household air pollution due to burning of solid fuels is responsible for over 65,000 premature deaths and more than 3.1 million disability-adjusted life-years per year (Beyene *et al*. 2018). The deaths attributed to indoor air pollution are mainly due to lower respiratory tract infections (36,144 cases in 2016), with the greatest impact in the first six days of life. Household air pollution is also a risk factor for chronic obstructive pulmonary disease, lung cancer and cardiovascular disease in adults and may be a risk factor for diseases such as tuberculosis and various adverse birth outcomes (World Health Organization [WHO] 2018). That is more than 150 deaths per day, with more than 90 per cent of them occurring in children under five years of age (Ministry of Water and Energy [MoWE] 2013). At the global level, 3.8 million people die prematurely in 2016 because of inhaling smoke from kitchens (WHO 2019).

Figure 4.24. Numbers of deaths attributable to indoor air pollution in 2016 in Ethiopia



Source: Beyene *et al*. 2018.

Table 4.49. Estimates of burden of disease attributable to solid fuel use in Ethiopia

Diseases or cases attributable to solid fuel use	Number of cases
ALRI deaths (<5 years)	50 320
COPD deaths (≥ 30 years)	6 140
Total deaths	56 460
Total DALYs	1 790 800
Percentage of national burden of disease	4.9

Notes: ALRI = Acute Lower Respiratory Infections, COPD = Chronic Obstructive Pulmonary Disease, DALY = Disability-Adjusted Life Year
Source: MoWE 2013.

In most Ethiopian households, cooking is done indoors and often during the night, creating a very smoky environment. This significantly affects women and children because they stay up longer than other household members and routinely spend more than four hours a day in the kitchen (MoWE 2013).

In poorly ventilated kitchens that use biomass fuels and unimproved stoves in Ethiopia, women are heavily exposed (Worku *et al*. 2016) to smoke for prolonged periods of time (often 1-3 hours). Around 91 per cent of women in rural areas in Ethiopia are estimated to be involved in cooking. Cooking exposes women and their young children to household air pollution andassociated health problems such as acute lower respiratory infections (Sanbata 2012). Particularly in rural areas, the unavailability of ventilation, overcrowding and family members' sharing of spaces in the house with domestic animals raise people's exposure to diseases (Worku *et al*. 2016).

In most rural settlements, dining, living and cooking are done in the same room (MoWE 2013). Almost 40 per cent of households cook in the housing unit where they live, while around 47 per cent use a separate building, and around 1 household in 10 (12 per cent) cooks outdoors (Ethiopia Central Statistical Agency 2017). This seriously affects people's health, causing acute respiratory diseases and eye infections.

BIOGAS

A substantial number of biogas owners in SNNPR have indicated that they are highly satisfied with the health benefits of biogas, while the health benefits indicated by users in Tigray and Amhara region were lower (SNV 2015). The reason for the lower satisfaction in Amhara is fuel stacking, which limits the benefits on health. This is discussed below.

Table 4.50. Health benefit satisfaction rate with biogas plant

Region	Satisfaction level		
	Not satisfied (%)	**Partially satisfied (%)**	**Fully satisfied (%)**
Amhara	5	59	36
SNNPR	3	-	97
Oromia	6	8	86
Tigray	17	8	75

Source: SNV 2015.

The main source of cooking energy before biogas was firewood, which is the most frequently used means of energy before installation of biogas. In SNNPR and Amhara, almost all survey participants indicated that they used firewood. In Oromia region, charcoal was the most widely used form of energy followed by firewood before biogas installation. National energy consumption data indicate that 80 per cent of household energy use is from firewood (SNV 2015).

The use of biogas has also led to a reduction of smoke in kitchens. Nationally, 20 per cent of respondents stated that smoke is completely avoided. When considered regionally, 55 per cent of survey participants indicated reduction to a greater extent, while 22 per cent of respondents indicated only some reduction. Overall, there is an indication that household pollution has been controlled at some level throughout the regions as a result of installation and use of biogas as a source of household fuel. As reported by 6 per cent of biogas users in Amhara region, the main advantages from using biogas compared to conventional fuel is that it causes less smoke so that it improves household air quality (SNV 2015).

The Ministry of Water, Irrigation and Energy ([MoWIE] 2018) has tried to assess the extent of smoke reduction due to the use of biogas, and the health impacts. Most of the biogas users believe that the smoke has been reduced and their health situation is improving. Around 19 per cent believe that smoke is completely avoided, while 38 per cent reported significant reduction in the smoke and health-related impacts. Regarding the occurrence of some smoke-related diseases, 67.9 per cent of the biogas users believe that eye disease was reduced, 57.9 per cent believe respiratory diseases were reduced, and 62.9 per cent believe cough was reduced.

An important aspect that must also be considered is the use of fuel interchangeably, or fuel and stove stacking. Most biogas users found that they continue to use wood, dung or charcoal even after the installation of biogas. They may use different fuels interchangeably due to shortage of energy caused by leakage of gas at fittings, improper biodigester feeding practice, as well as the dish preparation culture, such as baking injera and the coffee ceremony, for which the biogas fire outlet is not user friendly. Significantly, large number of users in Amhara (80 per cent) indicated they always use these items to complete household fuel requirements, as shown in Table 4.51. This considerably limits the health benefits of cooking with biogas.

Table 4.51. Use of wood, dung or charcoal for cooking after biogas

Practice	Amhara	SNNPR	Tigray	Oromia
Always use wood, dung or charcoal stove as well as biogas	80%	10%	15%	8%
Sometimes use wood, dung or charcoal stove	20%	88%	82%	79%
Fully cook with biogas	0	2%	3%	13%
Total	100%	100%	100%	100%

Source: SNV 2015.

According to the study done by MoWIE (2018), overall, 88 per cent of biogas users have observed significant improvements in the health conditions of their family members since they began using biogas energy. Higher levels of overall improvements in health conditions are observed in almost all surveyed regions, where the majority of respondents are satisfied with improvements in the health situation of their household members as a result of using biogas technology (MoWIE 2018).

IMPROVED BIOMASS COOKSTOVES

The use of improved cookstoves contributes to more efficient combustion and therefore less polluting smoke. No precise data were obtained for this report. Moreover, it is important to remember that improved biomass cookstoves are considered insufficient to meet the WHO guidelines on household air pollution (WHO 2014). The only cooking options that meet WHO guidelines at point-of-use are based on natural gas / biogas, LPG, electricity, ethanol and solar; the highest-performing advanced biomass stoves usually burn pellets.

4.15.6 Conclusions and recommendations

Synthesis of the findings

Household air pollution due to the burning of solid fuels is responsible for over 65,000 premature deaths and more than 3.1 million disability-adjusted life-years annually in Ethiopia. Diseases such as acute lower respiratory infection and chronic obstructive pulmonary diseases can be linked to household air pollution. Children under five years of age are particularly affected. The reduction in smoke in the kitchens of households cooking with biogas was clearly observed in user surveys. About 19 per cent of the households report that smoke is completely avoided, while 38 per cent report significant reductions in the smoke and health-related impacts. Overall, 88 per cent of respondents have observed significant improvements in the health conditions of their family members since they began using biogas energy. Improved cookstoves also contribute to reducing smoke.

The WHO considers improved biomass cookstoves to be insufficient to guarantee safe levels of household air pollution. Only cooking with natural gas / biogas, LPG, electricity, ethanol, solar, and the highest-performing advanced biomass stoves (usually burning pellets) permits the required low levels of pollution.

Practices and policies to improve sustainability

The Government of Ethiopia has a plan for energy sector development that recognizes the need to address household energy demands and reduce the devastating health, social and environmental impacts that arise from existing traditional energy sources and technologies. In particular, biogas technology offers an opportunity to address health conditions for women and children greatly by reducing household air pollution, increase gender equality by freeing up time spent on fuelwood collection, and provides commercial opportunities for local entrepreneurs in poor rural areas (MoWE 2013).

Given the number of cattle in Ethiopia, the potential of biodigesters is very high; it reaches more than 3.5 million units (Eshete, Sonder and ter Heegde 2006). Biogas can play an important role in reducing household air pollution from cooking, as well as the associated health risks. It is very important to disseminate information about the adverse health effects of household air pollution, especially for women and children, from the use of solid fuels and especially traditional biomass in inefficient stoves without chimneys or hoods. To promote the use of biogas, awareness should be raised, both among decision makers and the general population, about the benefits of this technology and the important role it can play in mitigating the adverse health effects.

Furthermore, it would be important to train biogas masons and cattle farmers on the construction and maintenance of anaerobic digesters and on the management of the digestate, to ensure that such digesters function correctly and efficiently and that their potential benefits can be fully exploited, including in terms of reduced household air pollution and reduced exposure to the pathogens contained in cattle manure. Also, regular refreshment training should be offered for biogas users on the maintenance and operation of biogas plants to increase the efficiency of the plants so that users obtain enough energy for cooking. The development of more advanced biomass cookstoves would be needed to guarantee lower levels of household air pollution.

More generally, the role of the Ministry of Health should be increased in the strategies to promote clean cooking solutions in Ethiopia, for example through an inter-ministerial committee.

Future monitoring

In Ethiopia, nationally representative data on health, particularly respiratory diseases, are very limited, and health data related to household smoke are even scarcer. This may be because collecting health data is expensive, and distinguishing the causal effect of smoke on health is complex. Gathering evidence on the causal effects of biogas consumption on health is challenging, as it would require long-term, costly studies based on a large sample of households. The effects of biogas use should be isolated from those of multiple other factors affecting the health of household members. However, there is adequate evidence regarding the negative health impacts of exposure to household air pollution due to the use of solid fuels and especially traditional biomass and stoves, and thus the positive effects of a transition to biogas are obvious.

In order to measure this indicator in the future, surveys and epidemiological studies on wood fuel use and the incidence of chronic obstructive pulmonary disease should be conducted. These should last for the minimum number of years that allows for the detection of changes in mortality and burden of diseases attributable to household smoke among a sample of households in different regions of the country. Another data source that might be useful in monitoring health problems and diseases related to fuel use is hospitals. Using this data, we could compare the incidence of diseases such as respiratory infections in areas with a high proportion of households using biogas and other areas, with similar environmental and socioeconomic conditions, with a low proportion. In this study, however, we were not able to obtain such data from hospitals, and to undertake this survey.

Detailed analysis of the use of fuel interchangeably (fuel and stove stacking) and the impacts on household air pollution also deserves more attention.

4.15.7 References

Beyene, G.E., Kumie, A, Edwards, R. and Troncoso, K. (2018). *Opportunities for Transition to Clean Household Energy: Application of the Household Energy Assessment Rapid Tool: Ethiopia*. World Health Organization. Geneva. Licence: CC BY-NC-SA 3.0 IGO. https://apps.who.int/iris/handle/10665/311280.

Esthete, G., Sonder, K. and ter Heegde, F. (2006). *Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia.* SNV Netherlands Development Organisation. Addis Ababa.

Ethiopia Central Statistical Agency (2017). *Ethiopia Demographic and Health Survey 2016.* https://dhsprogram.com/pubs/pdf/FR328/FR328.pdf.

Institute for Health Metrics and Evaluation (2014). *Global Burden of Diseases Database*. University of Washington. Seattle, WA.

Ministry of Water and Energy (2013). *National Programme for Improved Household Biomass Cookstoves Development and Promotion in Ethiopia.* Version 8. Addis Ababa.

Ministry of Water, Irrigation and Energy (2018). *Report on National Biogas Users' Survey*. Addis Ababa.

Sanbata H. (2012). *Indoor Air Pollution and Acute Respiratory Illness Among Children from Household fuel use in Addis Ababa, Ethiopia*. Addis Ababa University. Addis Ababa. 98.

SNV Netherlands Development Organisation (2015). *Report on Biogas Users' Survey (BUS).* National Biogas Programme of Ethiopia. Addis Ababa.

Worku T., Araya A., Frank G., Alemayehu W., Mehari W., Abera K. *et al*. (2016). Indoor and outdoor air pollution-related health problem in Ethiopia: Review of related literature. *Ethiopian Journal of Health Development*.

World Health Organization (2014). WHO Guidelines for indoor air quality: Household fuel combustion. https://www.who.int/airpollution/guidelines/household-fuel-combustion/en/.

World Health Organization (2019). Mortality from household air pollution. https://www.who.int/gho/phe/indoor_air_pollution/burden/en/. Accessed 27 May 2019.

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

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4.16.1 Description

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

4.16.2 Measurement unit(s)

Percentages

4.16.3 Overall methodology of the implementation

There is very limited information available on the incidence of occupational injury, illness and fatalities along biogas, firewood and charcoal use in Ethiopia, as well as for related sectors as whole. This may be due to a number of factors such as the scarcity of official reports, the lack of mandatory reporting schemes, and the absence of disaggregated statistics for bioenergy specific occupations. However, review of the limited investigation available on this aspect is presented from which preliminary lessons and recommendations can be drawn.

4.16.4 Key findings

Data concerning occupational injury, illness and fatalities that relate directly to the bioenergy sector in Ethiopia are lacking, as any relevant data are not disaggregated from other sectors. In the country, less concern for occupational safety is observed, for which low enforcement could be the major indicator. As in a report by the Ministry of Labour and Social Affairs (2015), in Ethiopia official data on accidents and injuries that relate to work are reported in aggregate and are for government developmental organizations only. There are no discrete figures for the agriculture sector or for the bioenergy sector (biogas and solid fuel).

The major risks that should be mentioned in the process of biogas production are explosion and fire (Sanja and Vesna 2013). In comparison to biogas, there are many risks associated with the production and use of charcoal. Fire accident is a common risk related to producing and using charcoal. The major risks related with charcoal production specifically are burn, puncher, exposure to smoke, dust and particulate matter, eye disease, and miscarriage. The risks related to charcoal use are headache, dizziness, comma, unconsciousness, convulsion and even death.

However, it is hard to find information about the sector's injuries, illness and fatalities specifically. The available compatible information for this specific indicator was referred from the survey conducted by SNV in 2015 and MoWIE in 2018.

- According to the survey, the case of fire accidents has been reduced by 98 per cent upon evolving biogas use as energy source; however, it would be misgeneralization to deduct that the biogas introduction alone resulted in avoided fire accidents. According to MoWIE (2018), 52.6 per cent of users believe that fire-related injuries were reduced, with 23.3 per cent saying they were significantly reduced and 29.3 per cent saying they were reduced.

- Before the installation of biogas, firewood was the major source of energy for 86.5 per cent of the respondents, while dung is mentioned as source of energy by 38.9 per cent. During discussions with biogas owners, the discussants mentioned that firewood and dung collection has multiple negative impacts on the families particularly for girls and women who are primarily responsible for such tasks. Extra work burdens, violence and children's delay from school are mentioned as some of the negative impacts. The survey also noted that the burden on children and women, and violence against girls and women, were major problems faced during firewood collection, as mentioned by 74 per cent and 26 per cent of respondents respectively (Table 4.52 and Table 4.53).

Table 4.52. Major problems and disadvantages people face while collecting firewood

Problems and disadvantages		Region				Total
		Amhara	SNNPR	Oromia	Tigray	
Children and women had extra burdens	Count	41	47	21	38	147
	%	76%	96%	48%	75%	74%
Girls and women were exposed to abuse and violence	Count	19	15	12	6	52
	%	35%	31%	27%	12%	26%

Source: MoWIE 2018.

Table 4.53. Occupational injuries encountered by the biogas user family during firewood collection

Occupational injuries encountered		Region				Total
		Amhara	SNNPR	Oromia	Tigray	
Injuries while collecting and carrying wood	Count	15	18	5	1	39
	%	28%	37%	11%	2%	20%
Exposed to wild animal attacks	Count	16	15	3	1	35
	%	30%	31%	7%	2%	18%

Source: MoWIE 2018.

4.16.5 Conclusions and recommendations

Synthesis of the findings

As material available for this specific indicator is scarce, the review mainly relied on a survey conducted within the SNNPR, Tigray, Oromiya and Amhara regions of the country, which showed that solid fuels were widely applied energy sources in those regions. In relation to this indicator the major risks highlighted by the survey were accidental fires and fire-related injuries, which were reduced following the introduction of biogas. In addition, exposure to violence and attack prevailed, especially for women and children while collecting firewood. No specific risks associated with charcoal production were mentioned.

Practices and policies to improve sustainability
Energy as well as health policies should include a clear mention of the mandatory character of reporting of illnesses, injuries and fatalities that occur while working in the bioenergy value chain in both private and governmental organizations. Inter-ministerial dialogue on this issue, particularly among the three most relevant ministries (i.e., Health, Energy and Labor) is relevant to come up with a clear description of the problem and better problem alleviation.

Future monitoring
Given the lack of official data on the matter, it is recommended to establish a nationwide long-term monitoring programme on occupational illnesses, injuries and fatalities disaggregated for the bioenergy sector. The programme should survey historic, if available, as well as current information, and collect data on injuries, illnesses and fatalities for future monitoring, which may last at least 10 years.

4.16.6 References

Ministry of Labour and Social Affairs (2015). *National Occupational Health Hazard 2013-2014 Report.* Addis Ababa.

Ministry of Water, Irrigation and Energy (2018). *Report on National Biogas Users' Survey.* Addis Ababa.

Sanja, S. and Vesna, N. (2013). Risk analysis in a biogas production plant*, CDQM* 16, 28-37.

SNV Netherlands Development Organisation (2015). *Report on Biogas Users' Survey (BUS).* National Biogas Programme of Ethiopia. Addis Ababa.

4.17 Indicator 17. Productivity

4.17.1 Researcher(s)

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4.17.2 Description

(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

4.17.3 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) \$/MJ (Birr/m^3) (\$/m^3)

4.17.4 Overall methodology of the implementation

This indicator focuses on the productivity of the land used to produce bioenergy, as well as the overall economic efficiency of the production. It focuses on supply rather than distribution and end-use.

Secondary data, retrieved from official reports and literatures, were used for both the biogas and solid biomass pathways. As regards biomass, the publications from the National Forest Sector Development Program of Ethiopia (NFSDP) and its 10-year programme (2017-2025) and the recent Ethiopian Forest Sector Review technical report were particularly useful.

4.17.5 Key findings

BIOGAS

Productivity
Biogas digesters being promoted and distributed to households in Ethiopia are mainly dependent on manure feedstocks. According to Tucho and Nonhebe (2015), there are more than 54 million head of cattle in Ethiopia. Bond and Templeton (2011) reported an average amount of 700 kg of dry dung per cattle per year. This results in production of 37.8 million tons of dry dung per year in the country. Unfortunately, cattle in Ethiopia are mostly range fed, and around 40 per cent of the dung produced is not accessible for collection. Hence, the total accessible annual dry dung is 22.68 million tons. Moreover, since biodigesters are in principle distributed to households with at least four head of cattle (Mengistu *et al*. 2016), the corresponding annual dung production of the household is estimated to be at least 2,800 kg of dry dung per year per household.

Agricultural residues and coffee processing wastes are the two other potential and competitive feedstocks for biogas production in Ethiopia. The total potential supply of agricultural residues in Ethiopia is about 22.4 million tons per year (Chala *et al*. 2018). Ethiopia is the fifth largest coffee producer in the world. Bickford (2019) indicated increased annual coffee production in Ethiopia, which was expected to reach 441,000 metric tons in 2019/2020 (435,000 tons in 2018/2019). Sime *et al*. (2017) estimate that for every 2 kg of coffee beans produced, approximately 1 kg of husk is generated. Therefore, 220,500 tons of coffee husks could be produced in 2019/20 and could theoretically be used for biogas production.

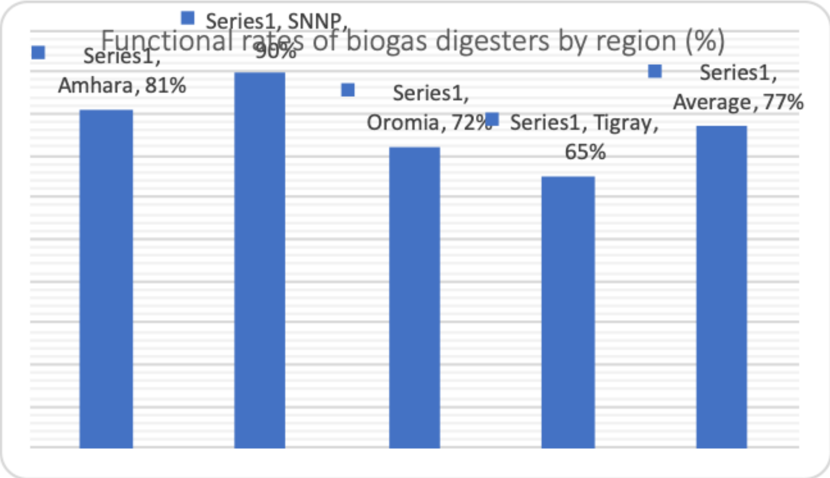
To date, cattle dung is the main biogas feedstock used for biogas production in the country and hence only the biogas amount from this feedstock is estimated here.

Processing efficiency
The most frequently distributed biodigesters in the National Biogas Programme of Ethiopia (NBPE) is the 6 m^3 biodigester known as SINIDU, a Nepalese model (Kamp and Forn 2016). It represents 89 per cent of all biodigesters distributed (Ministry of Water, Irrigation and Electricity [MoWIE] 2018). The programme, through its NBPE-I, NBPE-II and NBPE+ implementations, has already distributed a total of 22,166 biodigesters (Rai 2018). According to Seyoum (2018), around 2.83 $m^{3\ of}$ biogas is produced by this biodigester type per day, using 45 kg of dry dung. With the assumption that 1 m^3 of biogas has a calorific value of 22 MJ, the production of each biodigester reaches 1,384 MJ/ton of dry dung per day (2.83/0.0045 x 22).

Amount of biogas volume per year
A total of 22,166 biodigesters were already distributed to different regions of the country (Rai 2018). This corresponds to a daily producing capacity of 62,730 m^3 biogas per day or 22,582,721 m^3 of biogas per year, assuming the most frequent size of the biodigester (6 m^3). However, the household survey outcome of MoWIE (2018) revealed that only 77 per cent of the distributed biodigesters are

functioning due to lack of maintenance, change in farming practices, lack of water and lack of interest. The highest functionality rate in observed in SNNPR and the least in Tigray (Figure 4.25). As a consequence, biogas production is estimated at only 48,302 m^3 per day or 17,630,205 m^3 per year in the country.

Figure 4.25. Functionality rate by region



Source: MoWIE 2018.

Biogas production cost

The calculation is proposed for a 6 m^3 biogas digester. The cost assumptions are described in Table 4.54 (Fox 2018). Two levels of biogas production are considered (high and low). The resulting cost of biogas production is 0.9 to 2.1 birr/m^3 (0.0014 to 0.0032 $/MJ) taking into account the government subsidy, and 1.2 to 2.8 birr/m^3 (0.0018 to 0.0043 $/MJ) without the government subsidy (Table 4.54). This considers no labour cost and no discount rate.

Table 4.54. Cost of biogas production

Inputs				
Subsidy	6 000	birr		
Investment before subsidy	17 340	birr	867	birr/yr
Investment after subsidy	11 340	birr	567	birr/yr
Lifetime	20			
O&M, share of investment	2%		347	birr/yr
Biogas production (high)	2.83	m^3/day	1 033	m^3/yr
Biogas production (low)	1.2	m^3/day	438	m^3/yr
Results				
Annual cost w/o subsidy	1 214	birr		
Annual cost with subsidy	914	birr		
High biogas production				
Cost biogas w/o subsidy	1.2	birr/m^3	0.0018	$/MJ
Cost biogas with subsidy	0.9	birr/m^3	0.0014	$/MJ
Low biogas production				
Cost biogas w/o subsidy	2.8	birr/m^3	0.0043	$/MJ
Cost biogas with subsidy	2.1	birr/m^3	0.0032	$/MJ

SOLID BIOMASS

Productivity

Productivity of plantations depends on site/land productivity (quality), seed sources (genetic potential) and management. Land productivity is primarily determined by rainfall, topography and drainage pattern, influencing water availability and the length of the growing season. However, moisture limitation in drier areas can be overcome by irrigation, which greatly increases productivity because of a high level of radiation and good soils (Moges, Eshetu and Nune 2010). In brief, productivity will depend on the tree/shrub species type; species-site matching; silvicultural management practices; and energy conversion and utilization technologies. Wood fuel / solid biomass in Ethiopia is produced from natural forests (natural high forests, woodlands and area exclosures) and plantations (industrial and woodlots) owned by the government, private actors and communities.

Mean annual increment or productivity reaches 2.01 m^3/ha/year for natural forests, 12.5 m^3/ha/year for industrial plantations and 15 m^3/ha/year for woodlot plantations (Ministry of Environment, Forest and Climate Change [MEFCC] 2018a). The average national mean annual increment of all forests estimated would be 9.7 m^3/ha/year. The productivity of public plantations on a tree species basis has been Eucalyptu*s* (54 per cent of all species) at 18 m^3/ha/year, while cypress, pines and acacia species produce 13 m^3/ha/year.

The current estimated mean annual increment of 12.5 m^3/ha/year for industrial plantations is low compared to the potential growth of about 46 m^3/ha/year for Eucalyptus stands and 33 m^3/ha/year for conifer stands when planted and managed on productive sites (MEFCC 2018a).

The total annual sustainable productivity (yield) in 2017 was 32,171,470 m^3/year for natural forests of Ethiopia, 2,362,913 m^3/year for industrial plantations and 12,225,855 m^3/year for woodlot plantations (MEFCC 2018a) with a total amount of 46,760,238 m^3/year, where about 92.3 per cent of the total yield (an amount of 43,159,700 m^3/year) was used as fuel wood (firewood and charcoal).

The 10-year (2017-2025) national forest sector development programme of Ethiopia has planned establishment of forests and tree resources (7.2 million ha with a mean annual increment of 20 m^3/ha/year in five-year rotation) combined with the distribution of energy-saving cookstoves that can address the existing wood fuel demand and supply gap by the year 2025 (MEFCC 2018c). Moreover, sustainable management of existing natural forests and woodlands will contribute to the achievement of filling the wood fuel supply gap, while the forest cover of the country will reach 30 per cent of the total landmass by 2025 (MEFCC 2018c).

Processing efficiencies

Each type of bioenergy has a specific energy content (Table 4.55).

Table 4.55. Energy content of biomass fuels

Fuel type	Kcal/kg	MJ/kg
Fuel wood (17% mc dry basis, 14.5% wet basis, 1% ash)	3 700	15.5
Branches, leaves and litter (17% mc dry basis, 14.5% wet basis, 1% ash)	3 700	15.5
Roots (17% mc dry basis, 14.5% wet basis, 1% ash)	3 700	14.3
Charcoal (5.25% mc dry basis, 5% wet basis, 4% ash)	6 900	29
Saw dust (11% mc dry basis, 10% wet basis, 1% ash)	4 040	18.6
Agri-residue (11% mc dry basis, 10% wet basis, 5% ash)	3 585	15
Maize stalk (11% mc dry basis, 10% wet basis, 5% ash)	3 585	15
Dung (15% mc dry basis, 13% wet basis, 22.5% ash)	3 300	13.8
Comparison with fossil fuels		
Electricity	860	3.6 MJ/kwh
Kerosene	10 300	43
Diesel	10 300	43
LPG	10 300	45

Source: Woody Biomass Inventory and Strategic Planning Project [WBISPP] 2005a; WBISPP 2005b; Guta 2012.

As regards charcoal, its production with traditional earth-mound kilns incurs considerable losses, entailing four or five times as much energy input as would be required for burning wood directly (MEFCC 2018b). Charcoal conversion rates from wood are between 12-15 per cent for small experienced producers (Table 4.56) and 25 per cent for larger experienced producers (WBSIPP 2005a). Earth-mound kilns of around 4-7 m^3 capacity have been used throughout the country with a very low conversion efficiency (8-12 per cent), probably because of the small size of the kiln as well as the wood not being dried out properly due to fear of being caught by the forest authorities.

Table 4.56. Common charcoal production technologies used and conversion efficiency

No.	Production technique	Type of wood used	Average yield (charcoal production) of 1 m³ of wood (kg charcoal)	Average weight of 1 m³ of wood (kg wood)	Conversion efficiency in weight (%)	% of users of the techniques
1	Traditional earth-mound kiln	Dry/Semi-dry	62	430	14.4%	41.5%
2	Traditional earth-mound kiln	Wet	48	> 600	< 8.0%	14.0%
3	Traditional earth pit-kiln	Dry/Semi-dry	50	487	10.3%	34.1%
4	Traditional earth pit-kiln	Wet	25	> 600	< 4.1%	10.4%
5	Average	-	-	-	12.6%	100%

Source: MEFCC 2016.

Amount of bioenergy per hectare

In the case of firewood, the amount of bioenergy per ha is reflected in the productivity, described above. In the case of charcoal, the productivity depends on the productivity of the wood used for charcoal production; assuming a conversion efficiency of 12.6 per cent, the productivity of charcoal per ha is eight times less than the productivity of the wood used for charcoal production.

Production costs

Firewood and charcoal prices are different from production costs. For example, prices may include margin benefits. However, due to the lack of more detailed data on production costs, prices are used here as a proxy for production costs.

The gross production value of logs/roundwood was $74/m^3$ in 2013 (MEFCC 2017). The fuelwood selling price was 240 birr/m^3 (around $8/$m^3$), and the charcoal selling price was 1,840 birr/m^3 (around $63/$m^3$) in 2013 (MEFCC 2017).

According to MEFCC (2018b), the NFSDP, Pillar 2 (Sustainable production and value chains) cost-benefit analysis projection for the year 2017-2025, with the right interventions and policy adjustments the fuelwood harvest cost per m^3 from established commercial plantations with a mean annual increment of 22 m^3/ha/year will be $5, and the selling price per m^3 of fuelwood will be $21.5. In addition, fuelwood and bamboo culms harvest cost per m^3 from improved management of existing public industrial plantations and bamboo (highland and lowland) resources with a mean annual increment of 5.7 m^3/ha/year will be $5, and the selling price per m^3 of fuelwood and bamboo will be $12.6 (MEFCC 2018b).

A few words on the bamboo resources

Bamboo is a fast-growing, short rotation and high-yielding perennial grass with versatile uses for socioeconomic development and environmental protection, which makes bamboo important as an alternative to and supplement to wood in the country.

The two indigenous bamboo species in Ethiopia are *Yushania alpina* (*Arundin alpina*) K. Schum (Arundinoideae), and *Oxytenanthera abyssinica* (A. Rich.) Munro (Bambusoideae). They amount to 519,124 ha (MEFCC 2018a). According to a recent remote sensing-based inventory conducted by INBAR – Tsinghua University, Ethiopia has a total of 14,744.63 km^2 or 1.47 million ha of bamboo (INBAR 2018 cited in Environment, Forest and Climate Change Commission 2019).

Bamboo grows to its full height and diameter within one growing season of 2-3 months' time. It has a short rotation life and maturity age of around 3-7 years for construction and furniture purposes and can be harvested in 3-5 years versus 10-50 year rotations for most softwood and hardwood tree species. Bamboo attains an annual biomass increment of 10-30 per cent versus 2-5 per cent for trees (Ahmad and Kamke 2003; Sastry 2004; Bowyer *et al*. 2005).

In the north-western plantation bamboo forests of Ethiopia, the total biomass ranged from 65-117 tons/ha in dry weight basis with above-ground total dry weight of 56-99 ton/ha (Mulatu and Fetene 2012 cited in Mulatu, Alemayehu and Tadesse 2016a). In a natural bamboo forest of Masha, south-western Ethiopia, total above-ground biomass was in the range of 51-110 tons/ha (Embaye 2003; LUSO Consult 1997). The increment or biomass of less than one-year old plants investigated ranged from 6-26 tons/ha in north-western Ethiopia plantation forests and 8.6 tons/ha in Masha natural bamboo forest in south-western Ethiopia (Mulatu, Alemayehu and Tadesse 2016a).

In addition, 23 different bamboo species recently introduced in Ethiopia are under adaptability studies (Mulatu, Alemayehu and Tadesse 2016b). These species have been tested for their adaptability and growth performance in different locations, where some of them adapted and others are still under investigation. Businesses are being established to process bamboo, make value-added products and market these products in Ethiopia and abroad. However, powder-post beetle damage has been a serious problem for the bamboo and bamboo-based culm products in handcrafts, furniture industries and construction sectors.

4.17.6 Conclusions and recommendations

BIOGAS

Synthesis of the findings

The theoretical and accessible annual dry dung production in Ethiopia is 22.68 million tons. Agricultural residues and coffee processing wastes are the two other potential and competitive feedstocks for biogas production in Ethiopia. However, cattle dung is now the main biogas feedstock used for biogas production in the country; this is the focus of this indicator. The most frequently distributed biodigesters in the National Biogas Programme of Ethiopia is the 6 m^3 biodigester known as SINIDU. It produces around 2.83 m^3 biogas per day, or 1,384 MJ/ton of dry dung per day. A total of 17,388,695 m^3 per year of biogas production is reported, taking into consideration that only 77 per cent of all biodigesters work. The total cost of biogas production is 0.9 to 2.1 birr/m^3 (0.0014 to 0.0032 $/MJ) considering the government subsidy, and 1.2 to 2.8 birr/m^3 (0.0018 to 0.0043 $/MJ) without the government subsidy, depending on the biogas production level.

The analysis shows that biogas may be an effective option to replace fossil fuels and other less efficient and sustainable biofuels. Even if the cost of biogas production itself is low, the cost of building biogas digesters is high compared to the revenues of the households. Therefore, policies should be adopted to help the participating individuals, families and private sectors gain access to the necessary capital to build digesters. Moreover, a better understanding of the causes of non-functionality of some biodigesters needs to be developed.

Practices and policies to improve sustainability

Biogas in Ethiopia is still underutilized despite the supporting and promotion programme. Beyond the expansion of biodigester distribution, resulting in more biogas produced in Ethiopia, the overall productivity of the biodigesters can be increased through better use practices but also through the use of different potential feedstocks such as food processing and agricultural wastes.

Future monitoring

Obtaining data on biogas in Ethiopia is difficult but crucial for the expansion of the sector. Specifically, monitoring the productivity and the production costs are important to identify how to improve the quality of the biodigesters at each stage, from building to use, and how to select the best feedstocks to guarantee the highest productivity at the smallest cost. Systematic surveys must be implemented, specifically in the context of the National Biogas Programme, and the data must be systematically analyzed, organized and shared with the different stakeholders.

It is also important to remember that biogas production can provide many socioeconomic benefits, which should also be monitored. Some of these benefits are: new job opportunities, use of renewable energy sources from materials that would otherwise be disposed of, reducing the quantity of imported kerosene and other energy sources, and the generation of digestate reduces the use of inorganic fertilizers. These benefits deserve to be monetized and internalized in the computation of the production costs.

SOLID BIOMASS

Synthesis of the findings

The annual sustainable productivity/yield of natural forests in Ethiopia in 2017 was around 32 million m^3/year, of industrial plantations was around 2.4 million m^3/year and of woodlot plantations was around 12.2 million m^3/year, for a total amount of 46.8 million m^3/year. Around 92 per cent of the total mean annual increment, i.e., 43.2 million m^3/year, was used as fuel wood (firewood and charcoal). The mean annual increment or productivity of natural forests has been 2.01 m^3/ha/year, of industrial plantations has been 12.5 m^3/ha/year and of woodlot plantations has been 15 m^3/ha/year (MEFCC 2018a). The average national mean annual increment of all forests estimated would be 9.7 m^3/ha/year. The average wood-to-charcoal conversion efficiency is around 12.6 per cent.

Practices and policies to improve sustainability

Firewood and charcoal prices are different from production costs. However, due to the lack of detailed data, prices are used here as a proxy of the production costs. The fuelwood selling price was 240 birr/m^3 (around \$8/m^3), and the charcoal selling price was 1,840 birr/m^3 (around \$63/m^3) in 2013.

The decline of supplies from natural forests and the increasing demand for wood products will encourage farmers / tree growers and investors to cultivate an increasing number of fast-growing, high-yielding and short-rotation trees such as *Eucalyptus*, *Acacia* sp., *Grevillea*, cypress and pines. Increasing productivity of the available land by selecting the best (fast-growing, high-yielding and short-rotation) trees combined with good silvicultural and management practices are recommended solutions. Increasing the productivity of charcoal conversion kilns is also crucial; strategies for this purpose are presented in other indicators, such as Indicator 24 on training.

Inter-industry linkage (clustering and integration) of industries to be strategically located with respect to the distribution of the forest resource base is paramount. For example, it would be relevant to cluster a sawmill with an enterprise exploiting the by-products (branches, leaves and twigs;, off-cuts; and sawdust) and other non-timber forest products. This will help to maximize utilization products and create job opportunities for local communities near forests. This incldes planting fast-growing, high-yielding and short-rotation tree/shrub species while establishing fuelwood and commercial plantations for the purpose of improving the supply of fuel wood and charcoal as well as saw logs and other forest products.

The Ethiopian forest policy and strategy (2007), and the recent forest proclamation number 1076/2018, encourage farmers / out growers, communities and private investors to grow, manage and utilize forests for their different products including fuel wood and charcoal. It is believed that the policy and proclamation provisions will help to bring fuelwood plantations that will contribute to fill the fuelwood demand gap in the country.

Future monitoring

Getting data on firewood and charcoal production in Ethiopia is difficult since a large part of this production is informal. This information, however, is crucial in order to understand all of the drivers behind the productivity of the pathway, and to identify the best practices and the best feedstocks. Well-targeted surveys and studies would help better know the practices of charcoal producers and the best species to increase the productivity of the pathway.

4.17.7 References

Ahmad, M. and Kamke, F.A. (2003). Analysis of Calcutta bamboo for structural composite materials: surface characteristics. *Wood Sci Technol* 37, 233-240.

Bickford R. (2018). *Coffee Annual Report of Ethiopia*. GAIN Report Number: ET1904. US Department of Agriculture Foreign Agricultural Service, Global Agricultural Information Network. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Coffee%20Annual_Addis%20Ababa_Ethiopia_5-29-2019.pdf.

Bond, T. and Templeton, M.R. (2011). History and future of domestic biogas plants in the developing world. *Energy Sustain Dev*. 15, 347-54. http://dx.doi.org/ 10.1016/j.esd.2011.09.003.

Bowyer, J., Howe, J., Guiller, P. and Fernholz, K. (2005). *Bamboo Flooring. Environmental Silver Bullet or Faux Savior?* Dovetail Partners, INC.

Chala, B., Oechsner, H., Latif, S. and Müller, J. (2018). Biogas potential of coffee processing waste in Ethiopia. *Sustainability* 10, 2678; doi: 10.3390/su10082678.

Embaye, K. (2003). *Ecological Aspects and Resource Management of Bamboo Forests in Ethiopia.* Doctoral thesis. Swedish University of Agricultural Sciences, Department of Short Rotation Forestry, Uppsala.

Ethiopia Environment, Forest and Climate Change Commission. (2019). Ethiopia Bamboo Development Strategy and Action Plan (2019-2030). Addis Ababa.

Federal Democratic Republic of Ethiopia (2018). A proclamation to provide for the public-private partnership. *Federal Negarit Gazetta of the Federal Democratic Republic of Ethiopia*, No. 1076. Addis Ababa.

Food and Agriculture Organization of the United Nations (2011). *The Global Bio-energy Partnership Sustainability Indicators for Bio-energy*. First edition. Rome.

Forest Policy (2007). *Forest Development, Conservation and Utilization Policy and Strategy*. Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development. Addis Ababa.

Fox, R.B.S. (2018). Cost benefit analysis of small-scale biogas system development in Ethiopia. PowerPoint presentation. https://slideplayer.com/slide/13014511/.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia.* In cooperation with the Ethiopian Ministry of Water and Energy. Supported by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Guta, D.D. (2012). Assessment of biomass fuel resource potential and utilization in Ethiopia: Sourcing strategies for renewable energies. *International Journal of Renewable Energy Research* 2(1).

Kamp, L.M. and Forn, E. (2016). Ethiopia's emerging domestic biogas sector: Current status, bottlenecks and drivers. *Renewable and Sustainable Energy Reviews* 60, 475-488. doi: 10.1016/j.rser.2016.01.068.

Kassa, M. and Ewnetu, Z. (2014). *The Importance of Forestry in Ethiopia and the Need for Investing in the Sector to Meet National Goals and International Commitments.* Unpublished report. Addis Ababa.

LUSO Consult (1997). *Study on Sustainable Bamboo Management.* Commissioned by GTZ. Addis Ababa, Ethiopia.

Mengistu, M.G., Simane, B., Eshete, G. and Workneh, T.S. (2016). Institutional factors influencing the dissemination of biogas technology in Ethiopia. *J Hum Ecol.* 55(1,2), 117-134.

Ministry of Environment, Forest and Climate Change (2016). The Charcoal Industry Assessment of Ethiopia: Policy and Institutional Restructuring for Sustainable Charcoal. Supported by Global Green Growth Institute. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2017). *Ethiopia Forest Sector Review. Technical Report. Focus on Commercial Forestry and Industrialization.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018a). *National Forest Sector Development Program, Ethiopia. Volume I: Situation Analysis.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018b). *National Forest Sector Development Program, Ethiopia. Volume II: Program Pillars, Action Areas and Targets.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018c). *National Forest Sector Development Program, Ethiopia. Volume III: Synthesis Report.* Addis Ababa.

Moges, Y., Eshetu, Z. and Nune, S. (2010). Ethiopian forest resources: Current status and future management options in view of access to carbon finances. Literature review. Addis Ababa.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey, 2018.* National Biogas Programme of Ethiopia. Addis Ababa.

Mulatu, Y., Alemayehu, A. and Tadesse, Z. (2016a). *Biology and Management of Indigenous Bamboo Species of Ethiopia.* Ethiopian Environment and Forest Research Institute. Addis Ababa.

Mulatu, Y., Alemayehu, A. and Tadesse, Z. (2016b). *Bamboo Species Introduced in Ethiopia: Biology, Ecology and Management Aspects.* Ethiopian Environment and Forest Research Institute. Addis Ababa.

Rai S. (2018). *National Biogas Programme of Ethiopia (NBPE).* Addis Ababa.

Sastry, C. (2004). *Bamboo and Human Development.* Development express. Canadian International Development Agency, Policy Branch. Canada Communication Group. Canada.

Seyoum, S. (2018). *The Economics of a Biogas Digester.* Livestock Economics Division ILCA. Addis Ababa, Ethiopia. https://core.ac.uk/ download/ pdf/132634928.pdf.

Sime, W., Kasirajan, R., Latebo, S., Abera, M., Mohammed, A., Seraw, E. *et al.* (2017). Coffee husk highly available in Ethiopia as an alternative waste source for biofuel production. *International Journal of Scientific & Engineering Research* 8(7), 1874-1880.

Tucho, G.T. and Nonhebe, S. (2015). Bio-wastes as an alternative household cooking energy source in Ethiopia. *Energies* 8, 9565-9583; doi: 10.3390/en8099565.

Woody Biomass Inventory and Strategic Planning Project (2005a). *A National Strategic Plan for the Biomass Energy Sector.* Forest Resources of Ethiopia. Addis Ababa.

Woody Biomass Inventory and Strategic Planning Project (2005b). *Manual for Woody Biomass Inventory.* Addis Ababa.

4.18 Indicator 18. Net energy balance

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4.18.2 Description

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.

4.18.3 Measurement unit (s)

Ratios

4.18.4 Overall methodology of the implementation

The indicator provides a basis for identifying the most energy-efficient ways to produce bioenergy among a given set of options and may be used to choose appropriate technologies, feedstocks and practices. Among others, the indicator takes into consideration the energy inputs required by the production and the utilization of bioenergy at different stages of the value chain: the more energy consumed during the bioenergy life cycle, the less energy is available to meet other energy needs.

The Net Energy Ratio for each step of bioenergy production value chain has been calculated as follows:

$$\text{Net Energy Ratio} = \frac{\text{Total Energy Output}}{\text{Total Energy Input}}$$

Whereas, Total Energy Input = ∑ All energy required at each stage of production

A net energy ratio greater than one for a given bioenergy feedstock indicates that its production is sustainable from an energy perspective: the quantity of energy that the bioenergy can provide is higher than the amount of energy needed for its production.

It is also possible to calculate the Net Energy Balance:

Net Energy Balance = Total Energy Output – Total Energy Input

Secondary data, literature review and appropriate estimation have been used for both pathways in Ethiopia. Assumptions used for this indicator are the same as for Indicators 1 and 4, also based on life cycle analysis. As regards solid biomass, calculation considers two types of feedstocks: *Eucalyptus globules* and invasive *Prosopis juliflora* species. In Ethiopia, *P. juliflora* is an aggressive and the most invasive species in arid and semi-arid areas, and in pastoral areas. It has invaded large acreage of rangelands (Mehari 2008; Mehari 2015). Due to adequate resource availability and accessibility, its fast growing rate, high energy content and high yield in small area of land, *P. juliflora* is recommended for utilization as fuel wood and charcoal. Similarly, *Acacia decurrens* is also used for charcoal production in most areas of Ethiopia.

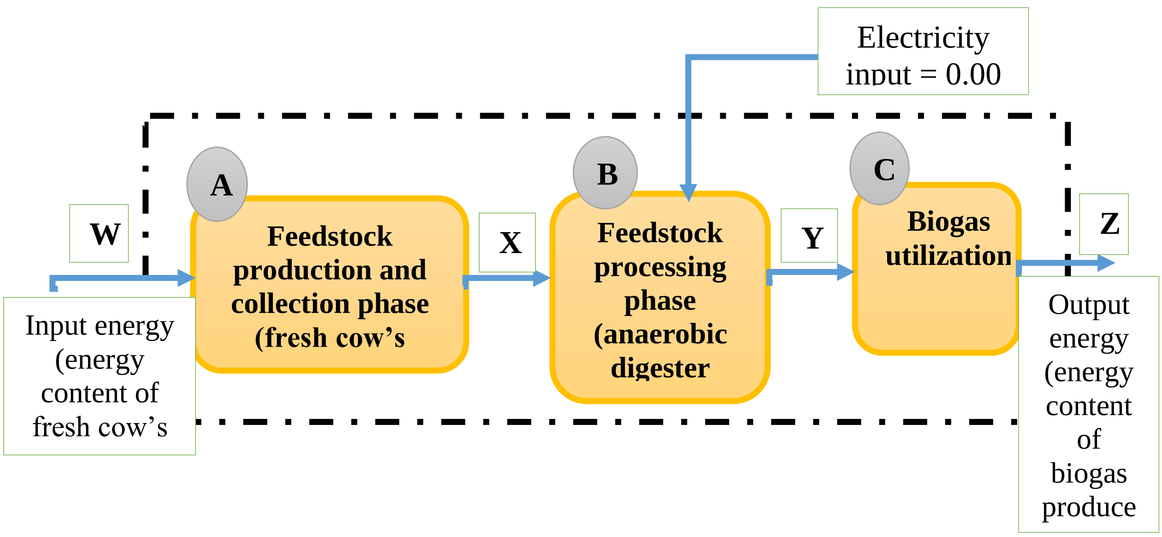
4.18.5 Key findings

BIOGAS

Basis of calculation for energy balance

The Overall System Boundary for calculation of the net energy balance is as follows:

Figure 4.26. Biogas production and utilization process flow diagram



The following data are considered in the analysis:

- Lower heating value of fresh cow's dung = 1.15 MJ/kg (Mehari 2015)
- 1 kg of fresh cow's dung = 0.04 m^3 biogas= 0.92 MJ biogas/kg
- 1 m^3 of biogas = 22 MJ energy
- Efficiency of biogas cookstove = 57 per cent (best case)
- Biogas losses due to leakages = 1 per cent (Indicator 1)

Feedstock production and collection (system boundary 'A' in fig. 1)

Since no energy consumption occurs in the collection and delivery of the fresh cow's dung to the anaerobic digester, the Net Energy Ratio does not apply and the Net Energy Balance of feedstock collection could be considered as equivalent to the lower heating value (LHV) of the fresh cow's dung, 1.15 MJ/kg. However, since fresh cow's dung is a waste, this sub-indicator is not really relevant.

Feedstock processing (fresh cow's dung) into bioenergy (system boundary 'B' in fig. 1)
Since the energy consumption input of the anaerobic digester and distribution of the biogas to the end users is zero, the Net Energy Ratio does not apply and the Net Energy Balance is 0.92 MJ/kg of fresh cow's dung

Biogas utilization (system boundary 'C' in fig. 1)
From the literature review, the efficiency of biogas stoves was found to be around 32 per cent, 44 per cent and 49 per cent for perfectly uncontrolled, semi-controlled and controlled conditions, respectively (Barfuss *et al*. 2013). In Ethiopia, the biogas cookstoves were found to deliver an efficiency of up to roughly 57 per cent in the semi-controlled test (Tumwesige *et al*. 2014). In general, the uncontrolled conditions better reflect the real conditions of use of the stoves, while the controlled conditions reflect a best case. The indicator is calculated for this best case, in a consistent manner with the other indicators.

The output energy at utilization level is calculated as follows, for an input of 0.04 m^3 of biogas, i.e., the gas produced by 1 kg of dung (the unit of kg dung is kept for comparison purposes along the full chain):

- Output energy (Z) = (Total energy per 0.04 m^3 input) x (Distribution efficiency) x (Cookstove efficiency) = 0.92 MJ/kg dung x 0.99 x 0.57 = 0.52 MJ/kg dung
- Net Energy Ratio = Output energy/Input energy = (Z/Y) = (0.52/0.92) = 0.56.
- This also represents the losses estimated by 0.99 x 0.57.
- Net Energy Balance = Lost energy (distribution and energy conversion) = 0.92-0.52 = 0.40 MJ/kg dung.

Life Cycle Assessment
The synthesis of the previous analysis concludes that the life cycle assessment energy balance is 0.3267 MJ/kg of dung since there is no energy consumption during feedstock production and feedstock processing.

Table 4.57. Summary of results of Indicator 18 for the biogas pathway in Ethiopia

Sub-indicators	Measurement scenarios		Unit	Results
18.1 (feedstock production)	Energy content of fresh cow's dung	A	MJ/kg dung	1.15
	Energy input for feedstock production (cow's dung)	B	kWh/kg dung	0
	Energy input for collection of fresh cow's dung	C	MJ/kg dung	0
	Net Energy Balance	A-(B+C)	MJ/kg dung	1.15
	Net Energy Ratio	A/(B+C)	Ratio	NA
18.2 (feedstock processing)	Biogas yield per kg dung	D	m^3/kg dung	0.04
	Energy input for biogas production	E	kWh/kg dung	0
	Energy output from biogas	F	MJ/kg dung	0.92
	Net Energy Balance	F-E	MJ/kg dung	0.92
	Net Energy Ratio	F/E	Ratio	NA
18.3 (bioenergy utilization)	Energy input, equivalent to energy losses (combustion + distribution)	G	MJ/kg dung	0.52
	Net Energy Balance	F-G	MJ/kg dung	0.40
	Net Energy Ratio	G/F	Ratio	0.56
18.4 (life cycle)	Net Energy Balance	Synthesis	MJ/kg dung	0.565

FUEL WOOD

Assumptions

- Basic density of fuel wood = 500 kg/m^3
- Energy content of fuel wood (air-dried) = approximately 14.5 MJ/kg or 7,250 MJ/m^3
- Energy content (lower heating value LHV) of *Eucalyptus globulus* feedstock =16.9 MJ/kg
- Energy content (LHV) of *Prosopis juliflora* wood = 17.03 MJ/kg. Energy content (lower heating value LHV) of *Acacia decurrens* feedstock = 3700 kcal/kg = 15.48 MJ/kg (Food and Agriculture Organization of the United Nations [FAO] 2001).
- No mechanical collection or logging
- Transportation: 0 km to rural households (89 per cent of the consumption), 70 km to urban households (11 per cent of the consumption), by platform truck (12 t, diesel); consumption is calculated in Indicators 1 and 4. Considering the average for rural and urban and the same assumption as in indicators 1 and 4: 2.23 MJ/t.km x 70 km x 11% = 17 MJ/t = 0.017 MJ/kg.

Table 4.58. The net energy balance for production and utilization of 1 kg fuel wood in Ethiopia in 2014, considering the average of urban and rural areas

Sub-indicator	Measurement scenarios		Units	Results		
				Eucalyptus globulus	***Prosopis juliflora***	***Acacia decurrens***
18.1 (feedstock production)	Energy content of fuel wood	A1	MJ/kg	16.90	17.03	15.48
	Energy input for collection of fuel wood	B1	MJ/kg	0.00	0.00	0.00
	Net Energy Balance	A1-B1	MJ/kg	16.90	17.03	15.48
	Net Energy Ratio	A1/B1	Ratio	NA	NA	NA
18.2 (feedstock processing and transport)	Energy content of fuel wood	A2	MJ/kg	16.90	17.03	15.48
	Energy input for processing and transport of fuel wood	B2	MJ/kg of wood	0.017	0.017	0.017
	Energy Balance	A2-B2	MJ/kg	16.883	17.013	15.463
	Net Energy Ratio	A2/B2	Ratio	994.117	1 001.76	909.588
	Traditional cookstove (thermal efficiency 10%)					
18.3a (bioenergy utilization)	Energy content of fuel wood	A3	MJ/kg	16.90	17.03	15.48
	Energy input, equivalent to energy losses (combustion)	B3 = A3 x (1-thermal efficiency)	MJ/kg	15.21	15.33	13.93
	Net Energy Balance	A3-B3	MJ/kg	1.69	1.70	1.55
	Net Energy Ratio	A3/B3	Ratio	1.11	1.11	1.11
18.4a (partial life cycle*)	Net Energy Balance		MJ/kg	NA	NA	NA
	Net Energy Ratio		Ratio	1.11	1.11	1.11
	Improved cookstove (thermal efficiency 20%)					
18.3b (bioenergy utilization)	Energy content of fuel wood	A4	MJ/kg	16.90	17.03	15.48
	Energy input, equivalent to energy losses (combustion)	B4 = A4 x (1-thermal efficiency)	MJ/kg	13.52	13.63	12.38
	Net Energy Balance	A4-B4	MJ/kg	3.38	3.40	3.10
	Net Energy Ratio	A4/B4	Ratio	1.25	1.25	1.25
18.4b (partial life cycle*)	Net Energy Balance		MJ/kg	NA	NA	NA
	Net Energy Ratio		Ratio	1.25	1.25	1.25

CHARCOAL

Assumptions

- Energy content (lower heating value LHV) of *Eucalyptus globulus* feedstock = 16.9 MJ/kg
- Energy content (lower heating value LHV) of *Acacia decurrens* feedstock = 3,700 kcal/kg = 15.48 MJ/kg
- Energy content (average) of *Eucalyptus* charcoal = 6,860 kcal/kg = 28.70 MJ/kg (Macksuel, Myla and Carlos 2018)
- Energy content (LHV) of *Prosopis juliflora* charcoal = 27.72 MJ/kg
- Energy content of *Acacia decurrens* charcoal = 27.20 MJ/kg
- Higher heating value (HHV) of charcoal = 32.33 MJ/kg with a standard deviation of 0.47 MJ/kg;
- No mechanical collection or logging
- Kiln efficiency = 17%
- Transportation: to kilns 5 km / from kilns to users 200 km. The energy consumption is calculated as in Indicators 1 and 4.
  To kilns: 2.23 MJ/t.km x 5 km / 1,000 = 0.011 MJ/kg wood.
  Kilns to households: 2.23 MJ/t.km x 200 km / 1,000 = 0.446 MJ/kg charcoal.
- Cookstove thermal efficiency: 10% traditional and 28% improved
- Share of cookstoves in the market: 80% traditional, 20% improved

Table 4.59. Net energy balance for production and utilization of charcoal in 2014

Sub-indicator	Measurement scenarios		Units	Results		
				Eucalyptus globulus	***Prosopis juliflora***	***Acacia decurrens***
18.1 (feedstock production)	Energy content of fuel wood	A1	MJ/kg wood	16.90	17.03	15.48
	Energy input for collection of fuel wood	B1	MJ/kg wood	0.00	0.00	0.00
	Net Energy Balance	A1-B1	MJ/kg wood	16.90	17.03	15.48
	Net Energy Ratio	A1/B1	Ratio wood	NA	NA	NA
	Energy input for transport of fuel wood (5 km)	A2	MJ/kg wood	0.011	0.011	0.011
	Energy losses in the conversion to charcoal (17%)	B2	MJ/kg wood	12.19	12.31	12.27
		B2	MJ/kg charcoal	71.7	72.5	72.2
	Energy input for transport of charcoal (200 km)	C2	MJ/kg charcoal	0.446	0.446	0.446
	Energy content of charcoal	D2	MJ/kg charcoal	28.70	27.72	27.20
	Energy Balance	D2-(B2+C2)	MJ/kg charcoal	-43.446	-45.2	-45.446
	Net Energy Ratio	D2/(B2+C2)	Ratio	0.397	0.38	0.37
	Traditional cookstove (thermal efficiency 10%)					
18.3a (bioenergy utilization)	Energy content of charcoal	A3	MJ/kg charcoal	28.70	27.72	27.20
	Energy input, equivalent to energy losses (combustion)	B3 = A3 x (1-thermal efficiency)	MJ/kg charcoal	25.83	24.94	24.48
	Net Energy Balance	A3-B3	MJ/kg charcoal	2.87	2.77	2.72
	Net Energy Ratio	A3/B3	Ratio	1.11	1.11	1.11
18.4a (life cycle)	Net Energy Balance	A3-B3-(B2+C2)	MJ/kg charcoal	-69.276	-70.2	-69.926
	Net Energy Ratio	A3/(B3+B2+C2)	Ratio	0.29	0.28	0.28

Table 4.59 (cont'd)

	Improved cookstove (thermal efficiency 20%)					
18.3b (bioenergy utilization)	Energy content of charcoal	A4	MJ/kg charcoal	28.70	27.72	27.20
	Energy input, equivalent to energy losses (combustion)	B4 = A4 x (1-thermal efficiency)	MJ/kg	22.960	22.176	21.76
	Net Energy Balance	A4-B4	MJ/kg	5.74	5.54	5.44
	Net Energy Ratio	A4/B4	Ratio	1.25	1.25	1.25
18.4b (life cycle)	Net Energy Balance	A4-B4-(B2+C2)	MJ/kg	-66.40	-67.40	-67.21
	Net Energy Ratio	A3/(B4+B2+C2)	Ratio	0.30	0.29	0.55

4.18.6 Conclusion and recommendations

BIOGAS

Synthesis of the findings

The biogas value chain does not include any energy consumption. However, energy losses occur at the level of biogas distribution (1 per cent) and at the level of the thermal efficiency of the stove (33 per cent for uncontrolled stoves; the efficiency could be as high as 57 per cent). Moreover, the production of the biodigester represents also a potential of efficiency improvement in order to produce more biogas per quantity of dung (0.04 m^3 biogas/kg dung/day).

Practices and policies to improve sustainability

The construction and installation of functional and productive biodigesters should be enhanced across the country. Several specific recommendations, such as a better training and even the certification of the masons, or the capacity-building of the users, are presented in other indicators, they are not repeated here. Cookstoves of highest efficiency should be promoted. This includes the capacity-building of the users (how to cook efficiently with biogas).

Monitoring

A better knowledge of the productivity of the biodigesters and the efficiency of the stoves, including information at the regional level, would help in identifying how to improve the quality of the biodigesters and therefore their productivity.

SOLID BIOMASS

Synthesis of the findings

The main losses occurring in the solid biomass value chain concern the conversion of wood into charcoal (efficiency of 17 per cent for the traditional kilns) and the losses associated with the stoves (low efficiency of 10 per cent to 20 per cent). The energy consumed for transport remains limited compared to the energy lost in energy conversion. Because of the losses associated with carbonization, the firewood pathway provides a better net energy balance.

Practices and policies to improve sustainability

The most important improvement potential concerns the carbonization technology: a more efficient carbonization than the traditional ones is needed (i.e., earth-mound and earth-pit). Firewood and charcoal cookstoves with highest efficiency should also be fabricated and promoted.

Future monitoring
For Indicator 17, a better knowledge of the firewood and charcoal value chain is crucial in order to understand all the drivers behind the energy balance of the pathway, and to identify the best practices and the best feedstocks. Regional and national bioenergy institutions need to work in collaboration to develop and design such a monitoring system.

4.18.7 References

Amare, Z.Y. (2015). The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District. *African Journal of Environmental Science and Technology* 9(4), 332-345. doi: 10.5897/AJEST2014.1838.

Barfuss, I., Gwavuya, S., Abele, S. and Müller, J. (2013). *Biogas Production vs. Dung Combustion as Household Energy in Rural Ethiopia.* University of Hohenheim, Institute for Agricultural Engineering in the Tropics and Subtropics, Germany.

Food and Agriculture Organization of the United Nations (2001). *Plantations and Wood Energy.* Rome.

Macksuel, F.S., Myla, M.F. and Carlos, R.S.J. (2018). Characteristics of wood and charcoal from *Eucalyptus* clones. *Floresta Ambient* 25(3). http://dx.doi.org/10.1590/2179-8087.035016.

Mehari, Z.H. (2008). *Invasion of* Prosopis juliflora *and (SW.) DC Rural Livelihoods. The Case of Afar Pastoralists at Middle Awash Area of Ethiopia.* MSc. Thesis. Norwegian University of Life Science, Oslo.

Mehari, Z.H. (2015). The invasion of *Prosopis juliflora* and Afar pastoral livelihoods in the Middle Awash Area of Ethiopia. *Ecological Processes* 4(13), doi: 10.1186/s13717-015-0039-8.

Ministry of Environment, Forest and Climate Change (2016). *The Charcoal Industry Assessment of Ethiopia*. Final report. Supported by Global Green Growth Institute. Addis Ababa.

Tumwesige, V., Fulford, D. and Davidson, G.C. (2014). Biogas appliances in Sub-Sahara Africa. *Biomass and Bioenergy*. http://dx.doi.org/10.1016/j.biombioe.2014.02.017.

4.19 Indicator 19. Gross value added

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4.19.2 Description

(19.1) Gross value added per unit of bioenergy produced and as a percentage of gross domestic product

4.19.3 Measurement unit(s)

US$/MJ, Birr/MJ and Percentage

4.19.4 Overall methodology of the implementation

BIOGAS

In Ethiopia, bioenergy is a relatively new sector and consequently comprehensive economic data on gross value added by this energy sector are scarce. Data collected by the National Biogas Programme of Ethiopia and SNV in different woredas of four regions (Tigray, Amhara, Oromia and SNNPR) were used. Review of key documents, interviews and discussions with experts of different institutions was done in order to explore all the necessary data available. Various study reports including those obtained from internet facilities, project documents, articles, etc. were also used. The institutions from which different sets of data was collected were the Ministry of Mines, Petroleum and Natural Gas, the National Biogas Programme for Ethiopia, the Ethiopian Electric Power Corporation, the Ethiopian Central Statistical Agency (CSA), the Ethiopian Petroleum Agency, the Transport Division at the Ministry of Transport, the Ministry of Agriculture, the Universal Rural Electric Access Program, the Ethiopian Rural Energy Development and Promotion Centre and others.

SOLID BIOMASS

Data from the joint study of the Ministry of Environment, Forest and Climate Change (MEFCC) and the United Nations Environment Programme were considered (United Nations Environment Programme [UNEP] 2016). Moreover, a review of key national documents and discussions with experts from different institutions linked to this energy sector was done, in order to collect all the necessary data used in the study. The data were obtained mainly from institutions such as the Environment, Forest and Climate Change Commission of Ethiopia (the then Ministry of Environment, Forest and Climate Change), the Bureaus of Environment, Forest and Climate Change of different regions, and others. Various national reports including those obtained from internet facilities, national and regional project documents were also used in the analysis.

4.19.5 Key findings

BIOGAS

Breakdown of the costs
According to the National Biogas Programme of Ethiopia (NBPE), households having a minimum of four head of cattle can adequately feed at least the minimum recommended domestic digester size (4 m^3) (Mengistu 2016). The biogas digester is reasonably priced compared to other energy sources. The average cost of a biodigester as per 2018 figures ranges from 13,888 birr ($473) to 21,719 birr ($740) for the 4 m^3, 6 m^3, 8 m^3 and 10 m^3 sizes.

The 6 m^3 is the most popular size; its average cost is 16,366 birr ($558). The breakdown of the cost of the 6 m^3 biodigester is (NBPE 2018):

- construction materials = 36 per cent (5,892 birr);
- pipes, fittings, appliances, etc. = 23 per cent (3,764 birr);
- and labour cost= 41 per cent (6,710 birr).

In Ethiopia, the cumulative installations of anaerobic digesters until September 2018 reached 22,166. The share of regional states was Amhara 33 per cent, Oromia 25 per cent, SNNPR 19 per cent, Tigray 23 per cent and New Regions 0.3 per cent (NBPE 2018). The outcome household survey (Netherlands Development Organisation [SNV] 2018) revealed that 77 per cent of biogas plants were functional, with variation among surveyed regions. The survey report stated that around 90 per cent of biodigesters installed in SNNPR were functional followed by 81 per cent reported from Amhara region respondents. Biodigesters distributed and installed in Oromia and Tigray regional states were functional at 72 per cent and 65 per cent, respectively.

Gross value added of biogas value chain
Biogas production in Ethiopia is at the household level. There is no industry-level production of biogas energy in the country. Therefore, the study focused on the household-level production and gross value added. The gross value added per unit of bioenergy at household level was measured using the data from Table 4.60.

On average, an anaerobic digester with a volume of 6 m^3 generated value-added from savings on fuel and fertilizers of 10,290 birr ($365). According to the result from Table 4.61, the gross value added per unit of biogas produced in Ethiopia is 0.45 birr/MJ of biogas fuel ($0.016/MJ). Thus, the total gross value added generated by the 22,166 anaerobic digesters currently in operation at household level was estimated at 175.62 million birr ($6.23 million).

In addition to the above result, the results of the survey conducted by SNV show that biogas users have reduced the use of fertilizer by 50 per cent. Thus, taking into account the increase in the cost of fertilizer and the reduction in use of fertilizer by biogas owners, the average savings from the cost of fertilizer for a farmer nationally was 35 per cent. Biogas users have indicated overall that they experienced a significant decrease in use of chemical fertilizer following installation of biogas digester. The decrease in the national average use of fertilizer was from 146 kg to 60 kg, or a 65 per cent decline (NBPE 2015).

Table 4.60. Gross value added from biogas (1)

No.	Content	Unit	2018	
			Birr	$
1	Cost savings per anaerobic digester / year	Birr/$	**11 850.00**	**420.00**
	Saving charcoal	Birr/$	3 600.00	128.00
	Saving firewood	Birr/$	1 500.00	53.00
	Saving kerosene	Birr/$	4 050.00	143.00
	Saving electricity	Birr/$	2 400.00	85.00
	Selling organic fertilizer	Birr/$	300.00	11.00
2	Benefit from increased crop yield	Birr/$	**2 717.00**	**96.00**
3	Operation cost of biogas per anaerobic digester / year	Birr/$	**2 966.00**	**105.00**
4	Maintenance cost	Birr/$	**1 311.00**	**46.00**
5	Gross value added per anaerobic digester	Birr/$	**10 290.00**	**365.00**
6	Number of anaerobic digesters in the country (functional biogas plants = 77% of total biodigesters)	Number of plants	22 166	22 166
7	Gross value added of biogas produced	Birr/$	**175 619 430.00**	**6 229 455.00**
8	Total biogas production at household level (2)	m^3/year	**17 630 230**	**17 630 230**
		MJ/year	**387 865 060**(3)	**387 865 060**
9	Gross value added per unit of biogas produced	Birr/$/MJ	**0.45**	**0.016**

(1) Construction costs were not included in the secondary data used for this indicator. The analysis is made after the construction of the biodigester. As a reminder, the cost of the biodigester is covered by the governmental subsidy in some regions of Ethiopia. (2) The average daily production of biogas is 2.83 MJ/m^3, as used in other indicators.
(3) It is calculated as 22,166 biodigesters x 0.77 in use x 2.83 m^3 biogas /day x 22 MJ/m^3 x 365 days = 387.865 million MJ/year
Source: Computation using data obtained from Gaddisa 2011; NBPE 2018; SNV 2018.

Percentage of gross domestic product

The gross value added from all biodigesters in Ethiopia at the household level was estimated at 176 million birr ($6.23 million) in 2018. The GDP in Ethiopia was about 2,366 billion birr ($83.84 billion) in 2018 (https://www.statista.com). Therefore, the gross value added of biogas production accounts about 0.0074 per cent of the country's GDP in 2018.

SOLID BIOMASS

Some dynamics of the sector

Charcoal production and marketing in Ethiopia have always been almost entirely informally organized. The majority of informal charcoal producers are low- to middle-income or pure pastoral/agro-pastoral and mixed farming households living in the dry lowlands of Ethiopia (Geissler *et al*. 2013). Most charcoal coming to towns and cities is produced, transported and retailed illegally. It is transported to urban centres using trucks, automobiles, camels and donkeys. A charcoal inflow survey into Addis Ababa alone showed on average over 42,000 sacks of charcoal coming to the city each day (MEFCC 2016a).

The main actors directly involved along the charcoal marketing chains include producers, distributors/transporters, wholesalers, retailers and consumers. The transporters who come with light trucks buy up to hundreds of sacks of charcoal and sell to both retailers and directly to consumers. Their main sales are to retailers in major urban areas. The price of charcoal is much higher when purchased in small retail shops than in sacks. In some cases, consumers can buy directly from producers or distributors; depot owners are also engaged in retailing charcoal (Bekele and Girmay 2013). According to the same report, distribution of income and profit sharing in the illegal charcoal production-supply channel in Ethiopia is highly skewed towards the producers, who are earning around 75 per cent of the total revenue per bag (MEFCC 2016a).

Percentage of gross domestic product

Wood fuel is the most important forest product consumed in Ethiopia, with average wood fuel consumption per capita of 1.35 m^3/year. The GDP contribution of wood fuel consumed annually is estimated at $5,858 million (MEFCC 2016b), which is about 39,072.86 million birr per year at PPP[3] of 2013 (UNEP 2016), accounting for around 4.5 per cent of the GDP of that year. The gross value added from wood fuel (charcoal and firewood) increased to $6,419 million (46,827 million birr), accounting for the same share of Ethiopian GDP of 2013-14 (Table 4.61).

Based on the result of a joint study from the Ministry of Environment, Forest and Climate Change of Ethiopia (MEFCC) and the United Nations Environment Programme (UNEP 2016), it is estimated that the gross value of rural wood fuel production in 2015 was 34.2 billion birr, which is very similar to the Forest Sector Review's (MEFCC 2017) estimate of 35.5 billion birr for 2013. The findings estimate the costs to be equal to 3.4 per cent of gross production, giving a figure of 33.5 billion birr for value-added. The Forest Sector Review's estimate of 1.35 m^3 of wood fuel production per capita in 2013 (95 per cent firewood and 5 per cent charcoal) has been adopted as the basis for valuation, since it better reflects overall national conditions.

Table 4.61. Value added of wood fuel production

Year	Value added		Share of GDP
	Million birr	Million $	Percent
2011-12	30 855	4 781	4.1%
2012-13	39 078	5 858	4.5%
2013-14	46 827	6 419	4.5%

Source: UNEP 2016.

The annual volume of wood harvested for wood fuel was around 120.4 million m^3 of roundwood equivalent in 2015 (115.0 million m^3 used as firewood and 5.4 million m^3 for conversion into charcoal) (MEFCC 2017). This is about 60.2 billion kg of wood fuel consumed in the same year. Assuming that one kilogram of fuel wood generates an average of around 14.5 MJ energy, the wood fuel consumed in the country in 2015 generated about 873 billion MJ/year. The gross value of rural wood fuel production (60.2 billion kg) in 2015 is 34.2 billion birr. The resulting gross value added per unit of energy produced from solid biomass (wood fuel) in Ethiopia is 0.0392 birr/MJ of biogas fuel ($0.0059/MJ).

[3]As cited in the report on "*The contribution of forests to national income in* Ethiopia *and linkages with REDD+*, United Nations Environment Programme" the purchasing power parity of birr to US dollar was 6.670 in 2013. This figure is extracted from the World Bank Report.

Table 4.62. Gross value added from solid biomass (charcoal and firewood)

Content	Unit	2015
Total wood fuel production	m^3	120.4 million
Total wood fuel production	kg	60.2 billion
Average energy production	MJ/kg	14.5
Total energy production	MJ/year	873 billion
Gross value added	birr	34.2 billion
	birr	5.127 billion
Gross value added per unit of energy produced	birr/MJ	0.0392
	$/MJ	0.0059

Source: Computation using data obtained from UNEP 2016; MEFCC 2017.

4.19.6 Main conclusions and recommendations

BIOGAS

Synthesis of the findings

The gross value added from the value chain across all levels of biogas production at the household level for all biodigesters installed in Ethiopia was estimated to be 176 million birr ($6.23 million), while the country's GDP in the same year was about 2,366 billion birr ($84 billion). As a result, the gross value added from biogas production in the country accounts for about 0.0074 per cent of the GDP in 2018.

Practices and policies to improve sustainability

Currently, the biogas produced at the household level is used only in some parts of the country, benefiting some 180,000 rural people. A significant surplus potential of biogas feedstock is available, especially at the farm level. According to the National Biogas Programme of Ethiopia, around 1.1 million households are potential users of dung-based biodigesters. Using this biogas feedstock to cook is important, but it would also be important to supply the energy to the grid. This would increase the gross value added from biogas production and the contribution of the sector to the country's GDP. Therefore, power generation from biogas should be adequately supported in the context of sectoral policies at the national level.

Future monitoring

Collecting primary data for measuring the indicator at the household level is a challenge due to the lack of financial and time budgets to obtain the information required in this analysis. In the future, sample surveys and pilot studies should be undertaken to monitor the sustainability of the sector. Continuous monitoring of the biodigesters (how many biogas digesters work, how much biogas is produced) and of the use of biogas (amount of consumption, the proportions in which households use biogas) and other energy sources in Ethiopia.

SOLID BIOMASS

Synthesis of the findings

The gross value added from the value chain across all levels of wood fuel (charcoal and firewood) production at the national level in Ethiopia was estimated to be $5,858 million (39,073 million birr) in 2013, accounting for around 4.5 per cent of the GDP of the year. The gross value added from wood fuel (charcoal and firewood) increased to $6,419 million (46,827 million birr), accounting the equal share of the Ethiopian GDP of 2013-14.

Practices and policies to improve sustainability

The promotion of the use of improved cookstoves is crucial to increase energy efficiency and sustainability. This would contribute to the gross value added of Ethiopia.

Future monitoring
Due to a lack of fully fledged information and national data on forest resources in general and on wood fuel production in particular, analysis in this sector is a big challenge. In the future, national surveys and different pilot studies should be conducted to monitor the sustainability of the sector.

4.19.7 References

Bekele, M. and Girmay, Z. (2013). *Reading Through the Charcoal Industry in Ethiopia: Production, Marketing, Consumption and Impact.* Forum for Social Studies. Addis Ababa.

Gaddisa, B. (2011). *Biogas Production System Design for Condominium and Its Feasibility.* A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Energy Technology. Addis Ababa University. Addis Ababa.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

International Energy Agency (2013). *People Relying on Traditional Use of Biomass for Cooking.* Paris.

Mengistu, M. (2016). *Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia, the Case of Ofla and Mecha Woredas.* Addis Ababa University. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2016a). *The Charcoal Industry Assessment of Ethiopia: Policy and Institutional Restructuring for Sustainable Charcoal.* Supported by Global Green Growth Institute. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2016b). *Ethiopia's Forest Level Submission to UNFCCC.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2017). *Technical Report. Ethiopia Forest Sector Review. Focus on Commercial Forestry and Industrialization.* Addis Ababa.

National Biogas Programme of Ethiopia (2015). *Report on Biogas Users' Survey (BUS).* SNV Netherlands Development Organisation. Addis Ababa.

National Biogas Programme of Ethiopia (2018). *Presentation of Report on National Biogas Program of Ethiopia.* Presented by Saroj Rai, Team Leader, National Biogas Programme of Ethiopia. SNV Netherlands Development Organisation. Addis Ababa.

SNV Netherlands Development Organisation (2018). *Report on National Biogas Users' Survey*. National Biogas Programme of Ethiopia. Ministry of Water, Irrigation and Electricity. Addis Ababa.

United Nations Environment Programme (2016). *The Contribution of Forests to National Income in Ethiopia and Linkages with REDD+.* Nairobi.

4.20 Indicator 20. Change in consumption of fossil fuels and traditional use of biomass

4.20.1 Researcher(s)

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4.20.2 Description

(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.

4.20.3 Measurement unit(s)

(20.1) MJ per year and/or MW per year
(20.2) MJ per year

4.20.4 Overall methodology of the implementation

The use of locally produced biomass for bioenergy can displace the consumption of fossil fuels and/or traditional use of biomass for energy, which would have significant positive impacts on the economic development and energy security of a country or region.

The required data was obtained from both national and international statistics.

4.20.5 Key findings

BIOGAS

Substitution of fossil fuel by biogas (20.1)
Biogas contributes to replacing the use of fossil fuel (kerosene) consumed for lighting at the household level. About 3.2 per cent of the biogas produced is used for lighting, and this replaces kerosene (Teweldee *et al*. 2017).

The annual production of biogas was estimated to be 17,630,230 m^3, or 387,865,060 MJ/year, assuming that the average calorific value of biogas is 22 MJ/m^3.

Therefore, the amount of biogas used for lighting from the total biogas consumption of Ethiopia is equivalent to 3.2 per cent x 17,630,230 m^3/yr = 564,167 m^3 of biogas. This replaces 338,500 litres of kerosene annually, equivalent to 14,555 MJ/year assuming that the average calorific value of kerosene is 43 MJ/m^3 and that 1 m^3 of biogas replaces 0.6 litres of kerosene (National Biogas Programme of Ethiopia [NBPE] 2015). The price of 1 litre of kerosene is 16.35 birr. Therefore, the annual savings is 5,534,481 birr ($204,074 per year).

Substitution of traditional biomass by biogas (20.2)
Assuming that 96.8 per cent of biogas is consumed for cooking, a total of 17,066,062 m^3 of biogas is used for cooking substituting firewood annually. This replaces 102,396 tons of firewood (with open fires) annually, considering that 1 m^3 of biogas can replace 6 kg of firewood (with open fires) (NBPE 2015). 1 kg of firewood with open fires can generate around 1.5 MJ of final energy services (NBPE 2015). So, 102,396 tons of firewood can generate 154,594,564 MJ/yr. This is the amount of energy (in cooking energy services) saved by substituting firewood with biogas.

SOLID BIOMASS

Solid biomass for cooking does not replace fossil fuels. Therefore, sub-indicator 20.1 does not apply.

According to national forest sector development data, the annual consumption of wood is 115 million m^3 as firewood and 5.4 million m^3 as charcoal (MEFCC 2018). Thus, the total annual solid biomass energy (firewood and charcoal) consumption of Ethiopia is 120.4 million m^3.

Average firewood consumption is higher in rural households at 4,600 kg/year per household compared to urban households, which use an average of 3,400 kg/yr per household (Guta 2014). The average firewood consumption at the scale of Ethiopia, considering the share between the urban and rural population (20.6 per cent and 79.4 per cent respectively) is therefore 4,353 kg/household.

An average household saves around 575 kg of wood per year using the Mirt stove and 300 kg using the Tikikil stove. Around 1.375 million households currently have sustainable access to improved cookstoves in Ethiopia (GIZ/EnDev 2015). The minimum firewood saved using improved cookstoves is 300 kg/household**.**

The firewood saved thanks to these stoves is as follows:
300 x 1.375 = 412.5 thousand tons of firewood per year.

4.20.6 Conclusions and recommendations

BIOGAS

Synthesis of the findings
The annual production of biogas was estimated to be 17,630,230 m^3 in 2018. Of this, 3.2 per cent is used for lighting and replaces kerosene. This is equivalent to 338,500 litres of kerosene annually, or 14,555 MJ/year. The annual savings is 5,534,481 birr ($204,074 per year).

Assuming that 96.8 per cent of biogas is consumed for cooking, a total of 17,066,062 m^3 of biogas is used for cooking. This replaces 102,396 tons of firewood (with open fires) annually, considering that 1 m^3 of biogas can replace 6 kg of firewood (with open fires) (NBPE 2015).

Practices and policies to improve sustainability
Not all of the biogas produced is used for lighting or cooking. Some biogas is released inadvertently through leakages and improper management, and a proportion is also flared or vented. To avoid leakages and the associated methane emissions, improvements should be made in the technology used for anaerobic digesters. Along with the development of appropriate technologies, policies should be put in place to promote investments in power generators, including cogeneration.

Future monitoring
To monitor and synthesize data such as digester size, biogas technology and labour indicators, the Ministry of Water, Irrigation and Electricity along with the National Biogas Programme of Ethiopia should set up official statistical data monitoring on biogas from livestock at the central and local levels.

SOLID BIOMASS

Synthesis of the findings
Total wood (firewood and charcoal) consumption of Ethiopia was 120.4 million m^3 in 2018 according to National Forest Sector Development data. An estimate 412.5 thousand tons of firewood was saved by using improved cookstoves.

Practices and policies to improve sustainability
The main challenge for solid biomass energy sources is the lack of accounting for bioenergy products not traded in formal markets or for trade in off-grid rural areas. Charcoal production and marketing has always been almost entirely informally organized and implemented by the private sector. Prior to 1993, the state-owned Construction and Fuelwood Production and Marketing Enterprise (CFPME) had in theory the monopoly for charcoal production and marketing. In practice a great proportion of charcoal was produced and marketed “illegally” outside the state monopoly. After 1993 CFPME wound down its operations and was finally disbanded.

Future monitoring
The government of Ethiopia should enact policies that facilitate formal trading or markets for solid biomass. Further research on improved charcoal cookstoves should be done.

4.20.7 References

Energizing Development Ethiopia (2015). *GIZ/EnDev National Report on Improved Cook Stoves (ICS).* Addis Ababa.

Guta, D.D. (2014). Effect of fuel wood scarcity and socio-economic factors on household bio-based energy use and energy substitution in rural Ethiopia. *Energy Policy* 75, 217-227.

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Report.* Addis Ababa.

Ministry of Water, Irrigation and Electricity (2013). *National Report on Biomass Energy of Ethiopia*. Addis Ababa.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey.* Addis Ababa.

National Biogas Programme of Ethiopia. (2015). *Report on Biogas Users' Survey (BUS)*. Addis Ababa.

National Biogas Programme of Ethiopia (2018). Surveys conducted on biogas users in rural residents of Ethiopia. Addis Ababa.

Tewelde, G., Rahwa, G., Grmanesh, A. and Lemlem S. (2017). Biogas plant distribution for rural household sustainable energy supply in Africa. *Energy and Policy Research* 4(1), 10-20, doi: 10.1080/23815639.2017.1280432.

4.21 Indicator 21. Training and requalification of the workforce

4.21.1 Researcher(s)

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4.21.2 Description

(21.1) Share of trained workers in the bioenergy sector out of total bioenergy workforce.
(21.2) Share of re-qualified workers out of the total number of jobs lost in the bioenergy sector.

4.21.3 Measurement unit(s)

Percentage (per year)

4.21.4 Overall methodology of the implementation

The indicator gives information on the skills and training provided to the bioenergy workforce. It also reflects the ability of these workers to be re-employed by the bioenergy or other sectors, or requalified if they lose their jobs in the bioenergy sector.

The analysis in Ethiopia refers only to sub-indicator 21.1. A high importance was given to the capacities and skills of the workers to properly do their jobs in the bioenergy sector. This is crucial to the quality of the technologies and uses of bioenergy.

Sub-indicator 21.2 was not measured, because there are no documented files on requalified workers if they lose their jobs in the bioenergy sector.

The information was collected from secondary data, official statistics and interviews.

The number of trained workers covers any worker that has received any training for activities in the bioenergy sector including in a workshop, training course, certification programme, or that received a degree from a technical school or higher education institution in biogas and in wood fuel and charcoal in relation to improved cookstoves.

4.21.5 Key findings

BIOGAS

Overview

The National Biogas Programme of Ethiopia (NBPE) offers a package that includes orientation and technical training, as well as a subsidy that covers one-third of the upfront capital investment costs (United Nations Economic Commission for Africa 2015).

For the successful implementation of a new programme involving new technology and new approaches, such as the NBPE, the provision of training was indicated to be a key requirement (Ethiopian Rural Energy Development and Promotion Centre and Netherlands Development Organisation [SNV] 2008). Consequently, diverse training, such as mason training, biogas users' training on how to operate and do minor maintenance, bioslurry utilization training, supervisor training, refresher training for masons and supervisors, and biogas technician training were given to the different groups of actors involved in the implementation of the NBPE.

According to key informants from the NBPE and SNV Addis Ababa sources in 2019, more than 2,000 masons were trained and 319 experts who have degrees and diplomas in 381 wordas are working on biogas nationwide. Over 26,000 farmers took part in training activities on biodigesters in eight regions (Amhara, Oromia, SNNPR, Tigray Afar, Benishangul-Gumuz, Ethio-Somali and Gambella). In Ethiopia, under SNV programmes, 9,300 job opportunities were created until 2017 (Teune 2019). A deeper analysis is provided below.

Masons

According to key informants from the NBPE and SNV Addis Ababa sources in 2019, mason training was a priority requirement for the implementation of the programme. The total number of masons trained by the NBPE is 2,162 in the four regions where biogas technology was first introduced: 1,007 in Amhara, 345 in Oromia, 345 in SNNPR and 465 in Tigray. Of these, 715 masons are active, until the baseline cut-off date of March 2017. In the four new programme regions where biogas technology has been introduced recently, 27 masons were trained: none in Afar, 12 in Benishangul-Gumuz, 15 in Ethio Somali, and none in Gambella. Three masons are still active. In total, only 33 per cent of the trained masons are still active (Sak business and personal development 2018).

It is difficult to maintain trained masons within the NBPE, because they do not work exclusively on biodigester construction and are usually attracted to other construction activities where they can find larger profit margins (Kamp and Bermúdez 2016).

The masons are rarely grouped as local micro-enterprises. However there is consensus at the regional and federal level to leverage entrepreneurship.

Measuring the skills of the masons and the effectiveness of the trainings definitely needs independent research. However, as a proxy, the skills of the masons can be reflected in the quality of the biogas installations. According to Mengistu (2016), surveyed biogas adopters were asked whether the masons were skillful in constructing the biogas plants. While 86 per cent were skillful, the remaining 14 per cent were not skillful. The following pictures of biogas installations can also substantiate the existence of skill gaps with some masons. Some biogas plants have been constructed at improper sites, with dome casts high above the ground level, and a few biogas plants have toilet seats where the PVC pipes protrude above the concrete surface.

Biogas construction enterprises

The total number of biogas construction enterprises (BCEs) established is 75, out of which 5 (7 per cent of the total) are qualified BCEs with proper offices and minimum organizational shape and resource to conduct their biogas business. Amhara, Oromia, SNNPR and Tigray regions have established 35, 21, 7 and 12 BCEs respectively. However, it was also reported that individual masons were considered as BCEs. Out of the total BCEs established, the number of active BCEs operating currently are 19, and these BCEs have business plans. The remaining 51 BCEs are not active. There is no BCE established in the four new programme regions (Afar, Benishangul-Gumuz, Ethio-Somali and Gambella) where biogas technology is being introduced recently (Sak business and personal development 2018).

Appliance producers and importers

The availability of appliance producers and importers of appliances to biodigesters and biogas cookstoves are important indicators of the private sector development. According to key informants from the NBPE in 2019, the total number of appliance producers in the country is above 13, and all received formal training from SNV. They produce biogas stoves, biogas lamps and accessories, dome pipes, dung mixers, water drains, gate valves, etc. But they produce few types of accessories. The main reasons for production of few types of appliances are the lack of technical knowledge and skills by the manufacturers, and the limited demand for the appliances. There are three importers engaged in biogas business, based in Addis Ababa, one of which imports items, once selected through a tender process. The main appliance items being imported are ball valve, PVC tap, open/close valve, mud shower, mantle, pressure meter, connector, focus cover and glass holder (Zerihun 2014).

Biodigester users

According to Kellner, it is common that due to lack of knowledge and awareness, biogas users do not exploit the full potential of biogas plants (Kellner 2014). Bad habits such as irregular or insufficient feeding of the biodigester greatly hinder biogas production. Bioslurry utilization is poorly taught to biogas users by masons, although extension officers from the Ministry of Agriculture could perform this task. Training is very much effective for proper use of bioslurry (Araya 2014). But not all users have a clear understanding of the proper management of bioslurry, only 27 per cent of respondents received training on the use and management of bioslurry, and the remaining 73 per cent did not receive training (Yalemtsehay and Teshome 2016).

Figure 4.27. Dung stored in the inlet pit for later use has become dry

Source: Mengistu 2016.

Biogas user training is neither given uniformly to all biogas user households nor across all biogas programme implementing regions. In Amhara Region, user training is being given only to the head of biogas user household, dominantly men. In Tigray Regional State, user training was given more often to three members of a biogas user household (Mengistu 2016).

Other barriers are the high illiteracy rate and the large number of mother tongues in Ethiopia which makes training of masons, technicians and users more difficult. This problem is exacerbated by the fact that within Ethiopia more than 80 different mother tongues exist (Kamp and Bermúdez 2016).

SOLID BIOMASS

Forestry's contribution to employment generation is not well documented; however, people profit from forestry employment through firewood and charcoal collection. Fuelwood production is by far the largest employment generator accounting for nearly 50 per cent of the total forestry employment (Million 2001). No comprehensive employment data were found for the wood fuel sub-sector. It is reported that more than 276,300 jobs in this subsector have been created, but it was not specified whether these involved full-time or part-time employment (Bekele 2011).

Charcoal makers had never received any type of skills training to improve their efficiency and had never been approached to use better technology to reduce wastage during charcoal production. Currently, the charcoal activities along the market chain provide a total of 380,847 permanent jobs and 905,918 seasonal employment opportunities, amounting to a total of 1,286,765 people directly employed by the industry; with around 4 dependents per employee, the total beneficiaries could rise to around 5.4 million. The main actors directly involved along the charcoal market chains include tree owner, nursery owner, seed collector, charcoaler, labourer, truck owner, loader, bag producer, wholesaler, stove producer and stove retailer (Bekele and Girmay 2013).

According to data from the National Improved Cookstove Programme (NICSP), more than 15 million improved cookstoves were disseminated between 2005 and 2016. Of these, 27 per cent were closed mud stoves such as the Awramba, while 21 per cent were Mirt stoves, 14 per cent Lakech, 6 per cent Tikikil, 5 per cent Upesi and 1 per cent other stoves (Energypedia 2018). Several training activities related to these activities were organized:

- The UK Department for International Development (DFID) disseminated over 15,000 Mirt stoves and trained over 110 producers and installers, and over 30 stove production units were set up and running in 16 towns in the four targeted regions, namely Amhara, Oromia, SNNPR and Tigray, by the end of the project in March 1997 (MEGEN POWER Ltd [MGP] 2008).

- According to GIZ, from 1998 to 2008, 370 Mirt stove producers in 230 towns in four regions including Amhara, Oromia, SNNPR, and Tigray took training. The project set up and supported the establishment of a total of 339 Mirt stove production entrepreneurs. Of this total number of project-supported producers, 36 per cent are women. The analysis of the study on 34 producers (10 per cent of total number of producers) indicated that 65 per cent of them were unemployed before they joined Mirt business (MGP 2008).

- According to records kept by the Sustainable Utilization of Natural Resources (SUN) Energy Project Head Quarters in Addis Ababa to 2007, a total of 339 producers were trained between 1998 and 2007. With regard to producers' regional distribution, 50 per cent of them are located within Oromia National Regional State. The remaining 34 per cent and 16 per cent are located in Amhara and Tigray Regional States respectively. Overall, averages of 4.6 persons were working in each of the Mirt stove production workshops (MGP 2008).

- The GIZ-SUN project has organized and conducted several capacity-building activities in terms of awareness creation and technical training in anticipation of engaging interested stakeholders in the stove dissemination business. Technical stove production training was given to over 300 persons. Two workshops for awareness creation were also held, where over 160 representatives from 130 organizations participated (MGP 2008).

- EnDev Ethiopia focuses on market development and capacity-building of local and public stakeholders via trainings for producers to improve their technical, business and marketing skills and technology development improving stove designs (Dagnew and Rzehak 2015). More than 650 small-scale producers of energy-efficient cookstoves established their business in 310 districts in seven regions. These producers have sold about 1.2 million improved cookstoves (mostly Mirt and Tikikil stoves, for baking and cooking respectively) since 2006 (Energising Development Partnership [EnDev] 2018).

- World Vision Ethiopia (WVE), with financial support from World Vision Australia and Standard Bank, is implementing an Energy-efficient Cookstoves (Mirt and Tikikil) Scale Up Project in several rural areas in Oromia (10 area development programmes ADPs and SNNPR (2 ADPs). In this project, training were given to over 50,000 people cooperatives in development and improved cookstoves manufacturing, 290 cooperatives with 49,170 members were established, innovative financing were given to 2,473 women-owned enterprises, and 25 Mirt improved cookstove producers cooperatives were set up and established with full-fledged legal status. These producers cooperatives, in addition to providing employment opportunities for more than 300 rural people, have produced and sold 49,170 Mirt improved cookstoves in less than three years (WVE 2016).

- The Ethiopian Energy Authority (EEA) carried out, side by side, large-scale recruitment, training and capacity-building programmes to build a strong energy sector institution. The EEA conducted energy sector studies and implemented dozens of renewable energy development projects and programmes including cookstoves, solar PV-based rural electrification, biogas, a woody biomass inventory, new fuels (charcoal and briquettes) production and marketing (Netherlands Development Organisation [SNV] 2018).

- According to Water, Education, Economic Empowerment, Medical Care and Alliance ([WEEMA] 2016), training was given on Gonzye and Mirt clean cookstoves for community utilization in the Tembaro worda clean cookstove project. Sixty-one potters were trained to produce high-quality clean cookstoves, and four staff from the local Water and Energy Office participated in the training to increase their own knowledge and ability to provide ongoing support to the potters cooperatives. Some clean cookstoves produced by the trainees are purchased by WEEMA and distributed to selected members in the community to benefit their household health and financial stability, as well as promote sales and utilization in the wider community (WEEMA 2016).

- SNV Ethiopia, in its Strengthening Enabling Environment for Clean Cooking Sector of Ethiopia (SEECCS) project, took the initiative and supported the revision and development of the Clean Cook Stove and Clean Cooking Solution, Performance Requirements and Test Methods (ES 6085: 2019) document. This ES 6085: 2019 is applicable to cookstoves used for cooking/baking in domestic, small-scale enterprise and institutional applications. The standard is expected to transform the clean cooking sector through enhancing economies of design such as innovation, product and service quality, production and delivery. These collectively improve cooking safety, human health and protection of the environment (SNV 2019).

- Even though Ethiopia has done a lot on human capacity, there are some barriers and constraints for development of training on improved cookstoves. The Regional Energy Agencies employ a large crew of hundreds of energy experts throughout their portfolios and all the way down to zones and woredas. However, they very often face skill and technical capacity constraints, including a lack of engineers. At lower administrative levels (woredas) frequent staff turnover is reported in several woredas. Moreover, some woreda energy experts complain about issues pertaining to human resources management in general and lack of training opportunities and deployment to tasks that do not fall under their job description (SNV 2018).

Despite all these activities, the lack of locally developed and adapted technologies that fit with local conditions, and the lack of practical training experiences remain important barriers, among others, to the development of the sector (Ministry of Water and Energy 2012). Some ideas to improve the situation are provided in the conclusions and recommendations.

4.21.6 Conclusions and recommendations

Training is a key factor for the sustainability of the production, adaptation and adoption of new technologies like biodigesters and improved cookstoves to ensure their sustainability. Training must therefore involve producers, developers, sellers and users. It is also vital for the development of the private sector. However, training must be well-thought and well-organized to get the expected results, and the bioenergy sector must develop sufficiently in parallel in order to guarantee the retention of the workers in the sector.

BIOGAS

Synthesis of the findings
Ethiopia has reached strong achievement in the biogas sector in the last 20 years. Close to 2,200 masons were trained in the eight regions where biodigesters were and are being introduced. Around 26,000 users were also trained on biodigesters. However, 33 per cent of the biodigesters are not working properly due to the poor design and construction of the biogas installations and the inappropriate operation and maintenance by the users (Ministry of Water, Irrigation and Electricity 2018). This lack of basic skills of biogas masons and users is clearly the result of inappropriate or insufficient training (Mengistu 2016).

Moreover, the lack of technical training for biogas appliances producers and for biogas construction entrepreneurs is a barrier to the rapid development of the sector. At the same time, it is difficult to maintain trained masons in the sector (around one-third of the trained masons are still active in the biogas sector) since they do not work exclusively on biodigester construction and are usually attracted by other construction activities where they can find larger profit margins and bigger volumes of work.

Practices and policies to improve sustainability
Some of the recommendations to reinforce the sustainability of the sector through training are:

- Develop state agencies to provide training and awareness on biodigesters.
- Involve more systematically the private sector and the NGO community in the construction of the biodigesters. Provide them with sufficient support and regular training activities (not only one training).
- Reinforce the activities related to Training of Trainers (TOT) in the sector of the construction and supervision of the biodigesters.
- Pay special attention to the training and awareness of masons and users in rural areas with high illiteracy rates and many different mother tongues. Training activities must be well adapted to these specific conditions.

- Implement a certification process of trained masons, users and extension workers.
- Involve universities in the training.
- Provide on the spot intensive maintenance training to a few – e.g., three – educated, wise and committed farmers per rural *kebele*.
- Provide solid training and practical demonstrations to the users in order to ensure proper storage and utilization of the bioslurry. This could contribute to enhanced agriculture activities.

Future monitoring
Many biogas digesters are not functional due to lack of monitoring and follow-up, technical problems, reduced cattle size and shortage of water. It is physically difficult to inspect every biogas digester constructed. Therefore, the skilled mobile team randomly selects some per cent of plants to be visited every month. Appropriate forms and questionnaire should be developed to record information on the biogas digesters visited. Based on the report of this team, actors should discuss the problems with the biogas digesters and suggest necessary repair works. The mobile team technicians also identify masons, users and companies that require refreshment training. The institutions should take responsible for monitoring the overall training activities that should be implemented through annual plans and reports. They should disseminate a monitoring programmers' system on biogas plant users' skills, masons' construction skills, and experts' maintenance skills so as to fill the gap in training.

SOLID BIOMASS

Synthesis of the findings
Many different training activities on improved cookstoves have been developed in Ethiopia by many different partners. Over 51,000 people and 1,300 small-scale enterprises are trained to manufacture and distribute stoves in the country. However, several limits are identified: lack of training and maintenance facilities, inadequate technology development and adaptation capacity, weak technical expertise, limited participation of the private sector, insufficient participation of the ministries in the training on production and dissemination, lack of coordination among stakeholders and lack of well-coordinated training for all elements of the supply chain.

Practices and policies to improve sustainability
Ethiopia's current charcoal production, largely based on inefficient carbonization processes, is a threat to both the local (forestry) and global (climate) environment. The lack of awareness, training and education largely contributes to this situation. In contrast, if skilled communities and private practitioners grew trees for charcoal and harvested trees through proper management plans, the sector would become much more sustainable.

Some of the recommendations to reinforce the sustainability of the sector through training are:

- Develop a strong training plan and easy-to-use manuals for charcoal producers covering: good charcoal production practices, including improved kilns; methods of sustainable harvesting and field management of tree resources (tree and shrub species, optimal tree management, rotation periods); rules for a good marketing of their products. Many charcoal producers could easily be reached through community-based groups producing charcoal. The existing energy centres, through which farmers are trained, are important platforms that could be empowered for community technical capacity-building.

- Implement a wood fuel certification process that, among other things, ensures that charcoal is produced from sustainably managed forests. Implement also a cookstove certification process to guarantee the quality of the stoves. Any certification process requires solid training of all stakeholders, from decision makers to producers.

- Encourage farmers to form Community Forest Associations that coordinate the sourcing of seeds and seedlings, planting, management, awareness creation, and monitoring of charcoal production as a cash crop. Inform and train the local communities to plant trees to replace the old ones or the harvested ones.

- Establish a modern laboratory for cookstove testing and development.

- Implement training and education of the end-users, including the use and maintenance of the stoves.

- Document past achievements and experience by collecting, organizing and analyzing data and information; this would include charcoal producer surveys and household energy surveys, to estimate and document the quantitative and qualitative impacts of the projects, to better understand the actual patterns of use and preferences for future improved cookstoves.

- Build training and research institutions for clean and efficient cooking solutions to help raise awareness of stakeholder health, economic, environmental and gender benefits and the creation of job opportunities.

- Use the media to create public awareness. The country has a wide range of media celebrities such as those in music and drama, public gatherings such as in churches, and community meetings (Eder). All of these could serve as important channels for reaching producers, wholesalers, retailers and consumers with messages on topics ranging from forest management to efficient use of charcoal.

Future monitoring

The government should have experts who monitor the production, standards and performance of improved cookstoves. Standardization and testing of the fuel-related performance of improved cookstoves requires qualified experts. The actors should follow up on the sustainability and effectiveness of the training. Since the country has few experts, annual monitoring surveys are required to collect critical information on year-to-year trends in end-user characteristics, such as technology use, fuel consumption and seasonal variations. There should be written protocols for use of the instruments, sample field monitoring questionnaires, data collection forms and spreadsheet templates for entering and evaluating the data.

4.21.7 References

Araya, H. (2014). Interview with Hailu Araya, Ecological Organic Agriculture. Addis Ababa, Ethiopia.

Bekele, M. (2011). Forest plantations and woodlots in Ethiopia. *African Forest Forum Working Paper Series* 1, 12.

Bekele, M. and Girmay, Z. (2013). *Reading Through the Charcoal Industry in Ethiopia: Production, Marketing*. FSS monograph No. 9. Addis Ababa.

Dagnew, D. and Rzehak, N. (2015). *Improved Cook Stoves.* Energising Development (EnDev) Ethiopia. https://energypedia.info/images/8/80/Improved_Cookstoves_in_Ethiopia_%28EnDev%29.pdf.

Energising Development (2014). *Ethiopia Improved Cook Stove*. Energising Development. https://energypedia.info/images/8/80/Improved_Cookstoves_in_Ethiopia_%28EnDev%29.pdf.

Energising Development Partnership (2018). Country Project Ethiopia. https://endev.info/images/9/9a/Factsheet_EnDev_Ethiopia_EN.pdf.

Energypedia (2018). Ethiopia Energy Situation. https://energypedia.info/wiki/Ethiopia_Energy_Situation.

Ethiopian Rural Energy Development and Promotion Centre and SNV Netherlands Development Organisation (2008). National Biogas Programme of Ethiopia: Programme Implementation Document. Addis Ababa.

Kamp, L.M. and Bermúdez Forn, E. (2016). Ethiopia's emerging domestic biogas sector: Current status, bottlenecks and drivers. *Renewable and Sustainable Energy Reviews* 60, 475-488. doi:10.1016/j.rser.2016.01.068.

Kellner, C. (2002). *Manual for the Construction of a BioDigester, "LUPO" Design.* Edition for Ethiopia.

MEGEN POWER Ltd (2008). *Impact Assessment of Mirt Improved Biomass Injera Stoves Commercialization in Tigray, Amhara and Oromiya National Regional States*. https://energypedia.info/images/c/c5/Mirt_impact_assessment_rpt_final.pdf.

Melaku, B, Yibeltal, T. and Motuma, T. (2015). *The Charcoal Industry Assessment of Ethiopia: Policy and Institutional Restructuring for Sustainable Charcoal*. Supported by Global Green Growth Institute. Ministry of Environment, Forest and Climate Change. Addis Ababa.

Mengistu, M.G. (2019). *Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia: The Case of Ofla and Mecha Woredas*. http://etd.aau.edu.et/bitstream/handle/123456789/3866/Mulu%20Getachew.pdf. Accessed 22 March 2019.

Million, B. (2001). *Forestry Outlook Studies in Africa Ethiopia.* Addis Ababa.

Ministry of Water and Energy (2012), *Scaling-Up Renewable Energy Program, Ethiopia Investment Plan (Draft Final)*. Addis Ababa. https://www.oecd.org/env/cc/TADELE_FDRE%20Ethiopia%20Scaling%20-%20Up%20Renewable%20Energy%20Program%202012.pdf.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey.* Addis Ababa.

Sak business and personal development plc. (2018). Biogas Dissemination Scale-up Programme (NBPE+), Programme Baseline Study Report. Unpublished.

SNV Netherlands Development Organisation (2018). *Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia. Final Report. Strengthening the Enabling Environment for Clean Cooking.* Addis Ababa. http://www.snv.org/public/cms/sites/default/files/explore/download/eth-seeccs-review_of_policies_and_strategies_final_report.pdf.

SNV Netherlands Development Organisation (2019). *National Standardization Council Endorsed Clean Cooking Solution Standard*. http://ww.snv.org/update/national-standardisation-council-endorsed-clean-cooking-solution standard.

Teune, B. (2019). *Capability Statement – Clean Cooking and Heating.* SNV Netherlands Development Organisation. http://www.snv.org/public/cms/sites/default/files/explore/download/snv_flyer_cookstoves_conference_final.pdf. Accessed 18 May 2019.

United Nations Economic Commission for Africa (2015). *Inclusive Green Growth in Ethiopia: Selected Case Studies.*

Water, Education, Economic Empowerment, Medical Care and Alliance (2016). Clean cookstoves. https://www.weema.org/weema-wednesday/2016/9/30/clean-cookstoves.

World Vision Ethiopia. (2016). *Easing Women's Life With Energy Efficient Cook Stoves.* https://www.wvi.org/sites/default/files/Coock%20Stove%20Megazine%20May %2019%202016.pdf

Yalemtsehay, D. and Teshome, S. (2016). Socio economic and environmental benefits of biogas slurry. *Journal of Environment and Earth Science* 6(11). https: //pdfs.semanticscholar.org/6560/37534357fc8f702c72739b15d4601804ef95.pdf.

Zerihun, D. (2014). *Studies on Prospects and Challenges of Uptake of Domestic Biogas Technology (The case of SNNPR, Ethiopia).* A Thesis submitted to Indira Gandhi National Open University in partial fulfilment of the requirement for the degree in Master of Arts in Rural Development. Addis Ababa.

4.22 Indicator 22. Energy diversity

4.22.1 Researcher(s)

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4.22.2 Description

(22.1) Change in diversity of total primary energy supply due to bioenergy

4.22.3 Measurement unit(s)

Index (in the range 0-1)
MJ bioenergy per year in the Total Primary Energy Supply (TPES)

4.22.4 Overall methodology of the implementation

The contributions of biogas and solid biomass to energy diversity have been analyzed together. Data on TPES of Ethiopia is based on the Energy Balance of the International Energy Agency. 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 HI 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.

4.22.5 Key findings

The total primary energy supply of Ethiopia reached 51.54 Mtoe in 2016 (International Energy Agency 2018). Biofuels and waste include traditional uses of biomass (open fires), modern uses of solid biomass (improved cookstoves), biogas and bioethanol. Specific consumption levels are as follows:

- About 449 ktoe of biomass is used with improved cookstoves (Indicator 14).
- The annual production of bioethanol from sugar factories was 128,165,000 litres in 2014, equivalent to 65 ktoe (1 m^3 bioethanol = 0.51 toe) (Shanko 2014). Since more recent data is not available, the same amount was considered in 2016.
- 17,388,695 m^3 biogas is produced annually from the working installed digesters, equivalent to 7 ktoe (Indicator 17).

To assess the contribution of modern bioenergy to the diversity and security of the energy supply in Ethiopia, the country's Herfindahl Index was calculated in two cases: (1) with modern bioenergy as part of the TPES and (2) without modern bioenergy, assuming that the modern bioenergy is replaced by traditional bioenergy (Table 4.63).

Table 4.63. Herfindahl Index of the country with and without modern bioenergy

	With modern bioenergy			Without modern bioenergy		
Source of energy	**Primary energy (ktoe)**	**S**	**S^2**	**Primary energy (ktoe)**	**S**	**S^2**
Biofuels and waste	47 048			47 048		
Biomass (traditional)	46 452	0.9028	0.8151	47 048	0.9129	0.8334
Biomass (improved cookstoves)	449	0.0087	0.0001	-	-	-
Bioethanol	65	0.0013	0.0000	-	-	-
Biogas	7	0.0001	0.0000	-	-	-
Hydro, geothermal, solar)	950	0.0184	0.0003	950	0.0184	0.0003
Petroleum	3 265	0.0634	0.0040	3 265	0.0634	0.0040
Coal	272	0.0053	0.0000	272	0.0053	0.0000
Sum	**51 806**	**HI**	**0.8195**	**51 806**	**HI**	**0.8378**

The Herfindahl Index reached 0.8195 with modern bioenergy, compared to 0.8378 considering only traditional bioenergy. The contribution of the total modern energy to the energy diversity remains very small. The contribution of biogas to the diversity is insignificant. The country is still highly dependent on the utilization of traditional biomass energy sources; in summary, there is a low modern bioenergy share in a poorly diversified energy supply.

4.22.6 Conclusions and recommendations

Synthesis of the findings

There is no single indicator for energy security: availability, accessibility, adequacy, affordability of energy are interrelated aspects associated with energy security. The GBEP approach is to look at how potential interruptions to energy supply can be minimized, using a risk management approach based on the diversity of the energy supply: the higher the number of bioenergy sources, the more diversified and secure the mix of supply.

For this purpose, the Herfindahl Index was used for measuring the contribution of bioenergy to the diversity of the energy supply in Ethiopia. The Herfindahl Index with modern bioenergy reaches 0.8195; it reaches 0.8378 without considering the modern bioenergy in the TPES. These results indicate 1) the low diversity of the energy supply of Ethiopia (high value of Herfindahl Index); and 2) the very limited contribution, although positive, of modern bioenergy to the diversity and security of the energy supply due to the low levels of energy supply by biogas, solid biomass used in improved cookstoves, and bioethanol.

Practices and policies to improve sustainability

The high dependence of the energy supply on traditional biomass is risky for different reasons, including energy security. The modern bioenergy potential has not been fully exploited so far in Ethiopia. Biogas and bioethanol production have started only recently and are expected to grow in the future. This, combined with an accelerated penetration of improved cookstoves and improved practices to produce charcoal, will contribute to a higher diversity and therefore a higher energy security in Ethiopia. In other words, higher penetration of modern bioenergy will clearly contribute to the energy diversity and therefore the energy security of the country.

Future monitoring
Assessing the diversity of the bioenergy sources in the energy supply of Ethiopia 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.

4.22.7 References

International Energy Agency (2018). *World Energy Balances 2018*. OECD Publishing. Paris. https://doi.org/10.1787/world_energy_bal-2018-en (Ethiopia).

Shanko, M. (2014). *Target Market Analysis: Ethiopia's Small Hydro Energy Market.* https://www.giz.de/static/themen_umleitung/index.html.

4.23 Indicator 23. Infrastructure and logistics for distribution of bioenergy

4.23.1 Researcher(s)

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4.23.2 Description

(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.

4.23.3 Measurement unit(s)

(23.1) Number
(23.2) MJ, m^3, or tons per year; or MW for heat and power capacity
(23.3) Percentage

4.23.4 Overall methodology of the implementation

Since the biodigesters utilize the cattle dung nearby, and biogas produced by the biodigesters is used by the households engaged in the activity, there is no need to transport the feedstocks or the biogas outside the household. Therefore, Indicator 23 and its subcomponents are not fully relevant for the biogas pathway in Ethiopia. The analysis is rather focused on the access to the biodigester technology to help understand the challenges associated with the technology itself and the location of the biodigesters.

The distribution routes for firewood and charcoal are roads. Therefore, the indicators, as defined, are not fully relevant. Instead, the analysis focused on a more general assessment of the production areas and routes of charcoal and firewood production.

Appropriate data/information were extracted from official reports, literature and interviews with experts.

4.23.5 Key findings

BIOGAS

Current and future localization of infrastructure
Higher cattle populations are found in four regional states (Oromia, Amhara, SNNPR and Tigray) of Ethiopia. These are the states where more biodigesters were distributed. For future development, Oromia and SNNPR have higher potential. In addition to having more head of cattle, the regions also have huge lignocellulosic resources such as sawdust, coffee waste, grasses, fruit wastes, etc., which are also usable as modern bioenergy sources.

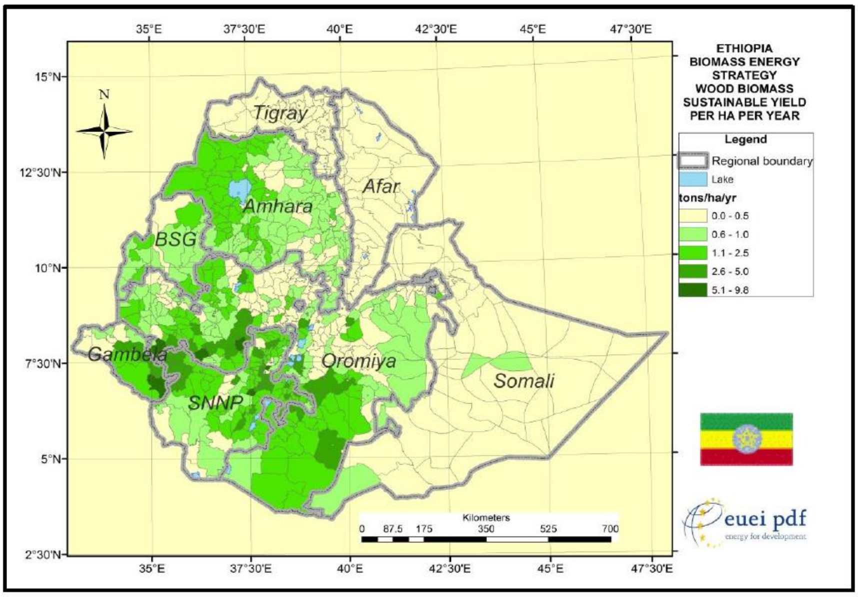
Design of biodigesters
Although there is no challenge with the logistics of biogas distribution, some difficulties exist regarding the local availability of technology and expertise to build the biodigesters, which could limit development of the infrastructure. Two common biodigester designs were installed in the country: SINIDU and SINDU 2008 (SAK 2018). SINIDU was the first design promoted and installed in the country, since the beginning of the Africa Biogas Partnership Programme. As a result, as of March 2017, almost 97 per cent of biodigesters were the SINIDU type, while the remaining 3 per cent were SINIDU 2008. Only three black-cotton soil digesters were installed in Oromia. As a relatively improved design, SINIDU 2008 has been rolled out in the country, and all recent installations were of this design type. There are different models available in other developing countries that could give better yield and are easier to handle.

SOLID BIOMASS

The need for transport: geographical correspondence between production and supply of firewood and charcoal
The total consumption of wood in Ethiopia is estimated to be 105.2 million tons in 2012. Oromiya, Amhara and SNNPR regional states consume 37 per cent, 23 per cent and 25 per cent of the total wood respectively (Biomass Energy Strategy Ethiopia [BESE] 2013). A total of 116 million m^3 of firewood was produced in 2013. The highest wood fuel use occurs around and to the east of Lake Tana in the Amhara region. High amounts of wood fuel are found along the Hareghe highlands and on either side of the Rift Valley in the SNNPR and Oromiya regions (BESE 2013).

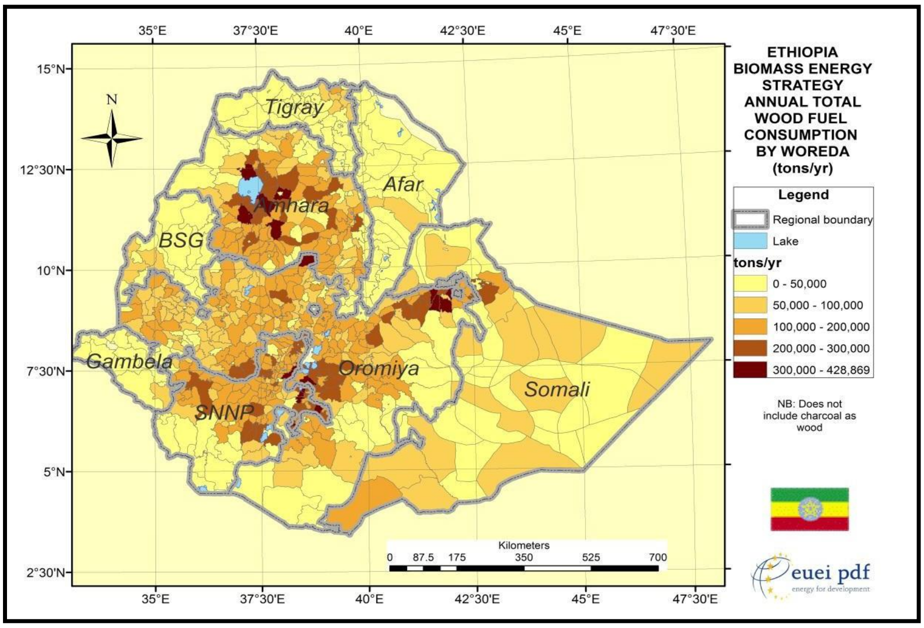
The comparison of Map 4.19 and Map 4.20 shows the need for firewood to be transported between some of the regions.

Map 4.19. Annual natural sustainable supply of woody biomass by woreda (tons/ha/yr)



Source: Biomass Energy Strategy Ethiopia 2013.

Map 4.20. Annual total wood fuel consumption by woreda (tons/yr)

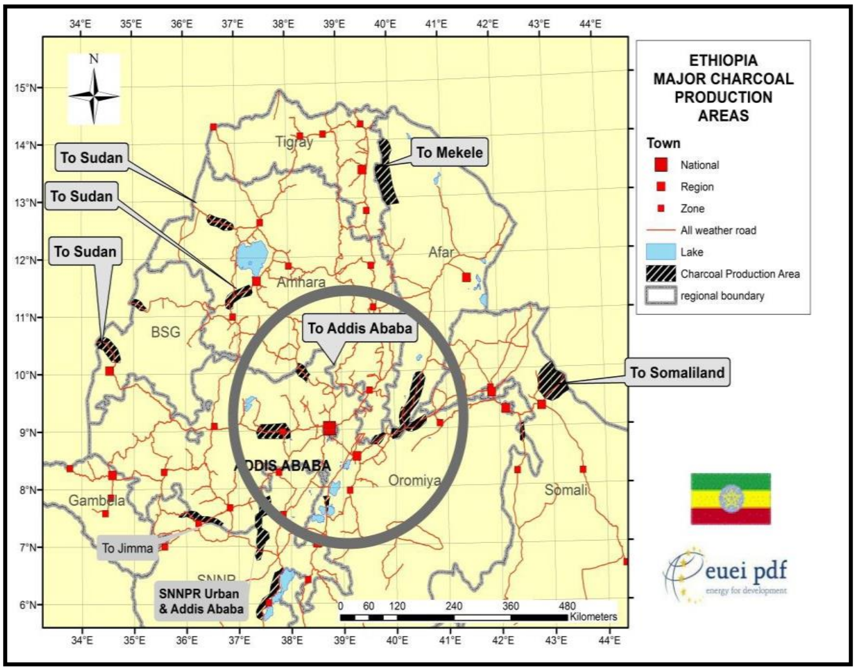


Source: Biomass Energy Strategy Ethiopia 2013.

The total consumption of charcoal in Ethiopia is estimated to be 5.7 million tons in 2012. The main charcoal production areas are Amhara (East Gojam, West Gojam, Agew zone and Gonder), Afar, Oromiya (Borena and Rift valley areas), SNNPR (Omo and Segen areas), Benishangul-Gumuz, and the Ethiopian Somali and Gambella regions. The main charcoal-consuming areas are in the Afar and Somali regions in the lowlands, and in the eastern Oromiya, Amhara and Tigray regions in the highlands.

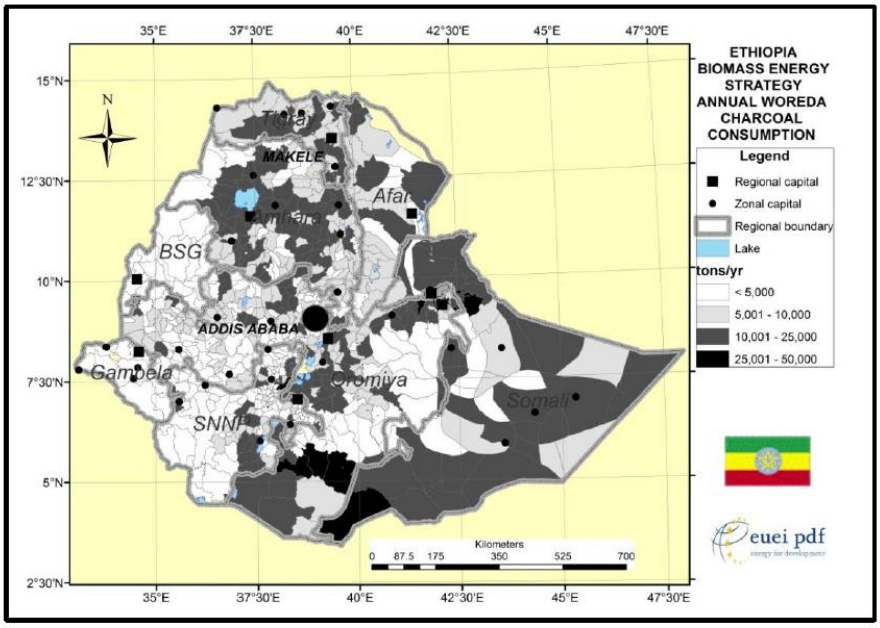
Ethiopia also illegally exports charcoal to Sudan, Djibouti, Somaliland and even the Middle East via Somaliland. The comparison of Map 4.21 and Map 4.22 shows the need for firewood to be transported between some of the regions.

Map 4.21. Main locations of charcoal production areas in Ethiopia



Source: Biomass Energy Strategy Ethiopia 2013.

Map 4.22. Annual total charcoal consumption by woreda



Source: Biomass Energy Strategy Ethiopia 2013.

Logistics for charcoal production
Charcoal production and marketing have always been almost entirely informally organized and implemented by the private sector. In practice a great proportion of charcoal is produced and marketed illegally. In total, there were an estimated 164 producer units in Ethiopia in 2016 (Table 4.64).

Table 4.64. Common wood sources for charcoal production by producer type in 2016

<table>
<tr><th>No</th><th>Production channel / Type of charcoal producer unit</th><th>Main sources of wood for charcoal making</th><th>No. of producer units</th><th>Production volume per year per producer</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Illegal organized large-scale producers (Lords) in W. Tigray, NW Amhara, Afar, Borana, Somali</td><td rowspan="2">Kebele/community natural forests, state forests, woodlands, community watersheds + trees on land leased for investment</td><td rowspan="2">41</td><td>4 000 to 7 120 bags for big urban centres</td></tr>
<tr><td>2 500 to 3 000 bags foreign trades</td></tr>
<tr><td>2</td><td>Licensed commercial charcoal producing enterprises or groups in W. Gojam and Awi zone</td><td>Wood purchased from private plantation and wood sellers</td><td>7</td><td rowspan="2">3 300 to 11 500 bags</td></tr>
<tr><td>3</td><td>Specially permitted commercial charcoal producing cooperatives (Wolkait Tigray)</td><td>Wood/forest cleared for big state development projects (sugar factories, dams)</td><td>5</td></tr>
<tr><td>4</td><td>Most regular individual and household-level regular large-scale producers /farmers and agro-pastoralists</td><td>Kebele/community forests, communal rangelands, state forests, woodlands including wood from protected areas</td><td>68</td><td>800 to 2 046 bags</td></tr>
<tr><td>5</td><td>Irregular household-level small-scale sporadic producers</td><td>State forests, national parks and conservation areas</td><td>40</td><td>103 to 570 bags</td></tr>
<tr><td>6</td><td>Few household-level producers</td><td>Own plantation / farm land</td><td>3</td><td></td></tr>
<tr><td></td><td colspan="2">Total</td><td>164</td><td>10 703 to 24 236 bags</td></tr>
</table>

Source: Charcoal Industry Assessment of Ethiopia.

Charcoal and firewood transport
Land transport is the main route for delivering charcoal and firewood from the production areas to end users either within the region or from one region to another in the country and neighbouring countries in the case of charcoal (Sudan, Djibouti and Somaliland). Both the charcoal and firewood production transport continue by trucks (Isuzu FSR), big trucks and local transport to different regions and neighbouring countries (Table 4.65).

Different producers use different means of transport/routes to deliver their charcoal to buyers. Charcoal transporters and smugglers in different production-supply channels ship varying volumes of charcoal per trip with different frequencies of transport and charge different fees per bag of charcoal.

A charcoal transporter who transports charcoal with a big private euro-truck (lorry) from large-scale illegal producers in Mille/Amibara woreda in the Afar region to Mekelle city in the Tigray region covers some 500 km per single trip. The quantity of charcoal transported by this carrier in a single trip is 1,400 bags, each weighing around 34 kg. With an average transport charge of 16.50 birr/bag/trip, the transporter earns a gross income of 23,100 birr per trip. With average frequency of two trips per month, this transporter delivers some 33,600 bags of charcoal from Afar to Mekele in a year.

Similarly, a charcoal transporter with a private Isuzu truck transporting charcoal from licensed producers in Faggeta-Lekoma in Awi zone (Amhara region) to Addis Ababa covers some 461 km per single trip. The average load of transport per trip is 300 bags, each weighing 25-30 kg, and the average frequency of transport per month is eight single trips. This amounts to an average delivery total of 28,800 bags of charcoal per year per transporter. With an average transport charge of 8 birr/bag/trip, the transporter earns an estimated gross income of 3,000 birr per trip.

A public transport minibus or small truck that transports charcoal from Abramo 01 in Assossa-zuria woreda to Assossa town covers 17 km and carries a maximim of 10 bags of charcoal per trip. With an average transport frequency of 16 times per month, this transporter delivers a total of 1,920 bags of charcoal to local charcoal markets at Assossa. Charging 10 birr/bag/trip, the transporter earns an estimated gross income of 100 birr per trip.

Table 4.65. Means of charcoal transport and quantity transported per trip by producer category

No.	Production channel	Charcoal source/ production area	Destination centre	Dis- tance in km	Means of transport	Average quantity transported per trip	Frequency of transport per month	Trans- port charge per bag	Total charge of transport /trip	Quantity of transport per year	People em- ployed per trip
1	Organized private large scale producers (Lords)	Mille or Amibara, Afar	Mekelle, Tigray	500	Rented big l trackers	1 400	2	16.50	23 100	33 600	2
		Yabello, Borana zone	Addis Ababa, Adama, Hawassa	570	Rented FSR	450	2	18.00	8 000	10 800	3
		Harshin, Jijiga	Dire dawa	250	Rented FSR	430	2	15.10	6 500	10 320	2
2	Licensed private/cooperative producers	FaggetaLeko, Awi, Amhara	Addis Ababa	461	Rented Isuzu	300	8	10.00	3 000	28 800	2
		Ambo-mesk, Mecha, Gojam	Bahir Dar	17	Rented Isuzu	250	2	5.00	1 250	6 000	2
3	Regular household producers	Humbo, Wolaita zone,	Shashemene	135	Isuzu from Arba Minch	50	12	10.00	500	7 200	2
	Regular household large-scale producers	Bena-tsemay, South Omo, SNNPR	Arba-minch	150	Isuzu or other passing by trucks	30	15	15.00	225	5 400	2
	Regular household/ medium-scale producers	Jogir, Gimbi, West Wollega, Oromia	Nekemte	47	Isuzu or other passing by trucks	30	4	5.00	150	1 440	2
4	Household small-scale producers Household/individual small-scale producers	Abramo 01, Assossa-zuria	Assossa town	17	Minibus or Bajaj	10	16	10.00	100	1 920	1
		Gongoma, Delo-Mena, Bale zone	Delo Mena town, Bale zone	14	Bajaj/Motor or rented animal-back	2	4	30	60	96	1
		Gol, Semen Bench	Mizan town, Bench	26	Own labour or donkey back	2	4	-	-	96	-

Source: Charcoal Industry Assessment of Ethiopia 2016.

4.23.6 Main conclusions and recommendations

BIOGAS

Synthesis of the findings

The three subcomponents of the indicator are not fully relevant for the biogas and solid biomass pathways given the nature of the distribution infrastructures: production and consumption of biogas at the same place, and land transport of firewood and charcoal. However, diversifying energy sources and transit routes for energy supplies remains fundamental for energy security.

As regards biogas, although there is no challenge with the logistics of biogas distribution, some difficulties may emerge due to the limited local availability of technology and expertise to build the biodigesters, which could limit the development of the infrastructure. Two common biodigester designs, SINIDU and SINDU 2008, were installed in the country.

Practices and policies to improve sustainability

With regard to biogas, increased diversity of the potential feedstocks, and the reinforcement of users' knowledge about the different feedstocks that can be used in the biodigesters, would increase the sustainability of the digesters. Promotion of the technology and expertise to build the biodigesters would also facilitate the development of infrastructure in different regions of the country. Moreover, the promotion of larger biodigesters, supported by private investors, deserves more exploration. This would create other types of distribution and infrastructure challenges (collection of the dung, for example), but it might generate more positive impacts.

SOLID BIOMASS

Synthesis of the findings

The main production areas of firewood occur around and to the east of Lake Tana in Amhara region. High amounts of wood fuel use are found along the Hareghe highlands and on either side of the Rift Valley in the SNNPR and Oromiya regions. The potential charcoal production areas in Ethiopia are Amhara (East Gojam, West Gojam, Agew zone and Gonder), Afar, Oromiya (Borena and Rift valley areas), SNNPR (Omo and Segen areas), Benishangul-Gumuz, and the Ethiopian Somali and Gambella regions.

In Ethiopia, charcoal production and marketing has always been almost entirely informally organized and implemented by the private sector. In practice a great proportion of charcoal is produced and marketed illegally. Charcoal production and marketing continue to be legally ill-defined.

Land transport is the main route for delivering charcoal and firewood from the production areas to end users either within the region or from one region to another in the country and neighbouring countries in the case of charcoal. Both the charcoal and firewood production transport continue by trucks (Isuzu FSR), big trucks and local transport to different regions and neighbouring countries.

Practices and policies to improve sustainability

There is currently no national policy/strategy for charcoal production, distribution and use in Ethiopia. Charcoal producers are informally organized, and they illegally produce and distribute charcoal. This leads to the unsustainable use of forest and to lost revenues for the country. In addition, the existing check point to control the illegal distribution of charcoal does not provide a consistent control. To alleviate these problems, capacity-building of the producers, sellers and distributers is needed, and the establishment of strong national policies and strategies is crucial. The charcoal producers, distributers and exporters should become legalized and certified. The establishment of a strong check point is also needed, with strict law enforcement to control the illegal distribution of charcoal. Legally organized exports of charcoal would also contribute to reducing the negative environmental impacts and increasing government revenues.

Future monitoring
This information on the supply and routes of firewood and charcoal is crucial to better understand the dynamics of the wood and charcoal markets and therefore apply appropriate measures. The creation of a legal market will contribute to better understanding of the quantities and routes of these feedstocks.

4.23.7 References

Ethiopia National Energy Policy (2013). Ministry of Water, Irrigation and Energy. Addis Ababa.

Ethiopian Forest Sector Review Technical Report (2017). Ministry of Environment, Forest and Climate Change. Supported by World Bank. Addis Ababa.

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia*. In cooperation with the Ethiopian Ministry of Water and Energy. Supported by European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Ministry of Environment, Forest and Climate Change (2016). *The Charcoal Industry Assessment of Ethiopia. Policy and Institutional Restructuring for Sustainable Charcoal*. Supported by Global Green Growth Institute. Addis Ababa.

Ministry of Environment, Forest and Climate Change (2017). Annual Report. Addis Ababa.

4.24 Indicator 24. Capacity and flexibility of use of bioenergy

4.24.1 Researcher(s)

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4.24.2 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.

4.24.3 Measurement unit(s)

Ratios

4.24.4 Overall methodology of the implementation

Unused or flexible capacity in using bioenergy (biogas, fuel wood and charcoal) contributes to overall energy security and can be considered as an aim for infrastructural development in bioenergy utilization. A high degree of flexibility in the use of bioenergy can translate into a rapid increase in bioenergy consumption under favorable economic conditions.

The ratio indicates the level of capacity for using bioenergy compared to the actual utilization. Assessing the ratio of flexible capacity that can use either bioenergy or other fuel sources to total capacity provides information on the flexibility of utilization systems to switch between bioenergy and other fuel sources.

Secondary data, literature review and interviews with energy experts were used. Actual data on the current level of utilization of both biogas and solid biomass (i.e., fuel wood and charcoal) were collected and organized. The collected data were analyzed, and the potential use of bioenergy across Ethiopia was computed accordingly. The involvement of and discussion with experts of the National Biogas Programme of Ethiopia (NBPE), the Ethiopian Ministry of Energy, Irrigation and Electricity, GIZ, SNV and other stakeholders was considered as a key step to obtain data on the national perspective for practical implementation of Indicator 24 in Ethiopia, as well as to assess the national-level capacity and flexibility of use of bioenergy for the selected bioenergy pathways.

Two approaches are proposed to assess the ratio of capacity for using bioenergy (24.1):

- The first approach assesses the potential to extend the installed capacity of biodigesters and improved biomass cookstoves to new households, compared to the current situation.

- The second approach relies on the concept of fuel stacking: the households with a biodigester or with improved cookstoves usually continue using traditional ways of cooking. The approach aims at measuring the magnitude of fuel stacking, and therefore, the potential of increasing the use of modern cooking solutions with bioenergy in the households already using those solutions but in a partial manner only.

4.24.5 Key findings

BIOGAS

The ratio of capacity based on the number of households with and without biodigesters is 48 per cent, assuming a potential of 45,400 households with biodigesters (Table 4.66). This potential represents the possibility of the current households having biodigesters. The value also increases over time proportionally with adequate resource availability and with accessibility to feedstock (i.e., fresh cow's dung) for biogas production and utilization.

The ratio of capacity based on fuel and stove stacking shows that around 67 per cent of the meals are cooked with other cooking methods (firewood, charcoal, etc.). This illustrates the potential to increase the use of the biodigesters in the households already cooking with biogas, under the condition that the quantity of biogas produced each day is sufficient.

The ratio of flexible capacity is assessed based on the capacity of the households to cook with several fuels or stoves, in addition to the biogas stove. It is considered that 100 per cent of the households with biodigesters have other cooking methods in parallel (firewood, charcoal, etc.). In other words, the ratio of flexible capacity is 100 per cent (all households can use another cooking method if needed).

Table 4.66. Ratio of capacity of the biogas pathway

Items		Year			
		2015	2016	2017	2018
Approach 1: Increase the number of households with biodigesters					
Current households with biodigesters [(1)]	a	12 938	15 491	18 480	22 166
Potential households with biodigesters	b	40 500	42 000	43 200	45 400
Ratio of capacity	a/b	0.32	0.37	0.43	0.48
Approach 2: Increase the use of the biodigesters by households already having a biodigester					
Number of meals cooked with biogas per week	c	3	3.5	5	7
Number of meals cooked with other fuels per week	d	18	17.5	16	14
Ratio of capacity	c/(c+d)	0.143	0.167	0.238	0.333

[(1)] More details in section 3 of the report (description of the pathway)

Source: National Biogas Programme of Ethiopia [NBPE] 2015; Rai 2018; Seyoum 2018; Netherlands Development Organisation [SNV] 2018; Ethiopia, Ministry of Water, Irrigation and Electricity 2018.

SOLID BIOMASS

On the supply level, the sustainable supply of wood fuel is estimated to be 32.1 million m^3/yr, and the remaining production (79.7 million m^3/yr) is sourced from unsustainable extraction (Ministry of Environment, Forest and Climate Change 2018). In other words, the ratio of capacity for sustainable solid biomass is 28 per cent.

On the utilization side, a similar approach is used as in the case of biogas, focusing on the use of improved cookstoves. The ratio of capacity is 8 per cent for improved cookstoves (Table 4.67), in other words, the potential to increase the use of improved cookstoves is very high. The number of households with improved cookstoves decreased in 2014 and in 2016. This is due to fuel stacking or switching of fuel utilization into biogas, fuel wood (i.e., open fire) and charcoal in different regions of Ethiopia, particularly, in Oromia region, SNNPR and Benishangul-Gumuz region.

The ratio of capacity based on fuel and stove stacking shows that around 71 per cent of the meals are cooked with other cooking methods, mostly open fires; this illustrates the potential to increase the use of the improved cookstoves in the households already having improved cookstoves.

The ratio of flexible capacity is also assessed based on the capacity of the households to cook with several fuels or stoves, in addition to the improved cookstove. It is considered that 100 per cent of the households with an improved cookstove have other cooking methods in parallel (firewood, charcoal, etc.). In other words, the ratio of flexible capacity is 100 per cent.

Table 4.67. Ratio of capacity of the solid biomass (fuel wood and charcoal) pathway

Items		Year			
		2013	2014	2015	2016
Approach 1: Increase the number of households with improved cookstoves					
Current households with improved cookstoves	a	1 687 520	1 514 429	1 606 942	1 494 145
Potential households with improved cookstoves	b	18 124 650	18 343 315	18 521 680	18 764 122
Ratio of capacity	a/b	0.093	0.082	0.087	0.079
Approach 2: Increase the use of the improved cookstoves by households already using an improved cookstove					
Number of meals cooked with improved cookstoves per week	c	2.5	3.5	5	6
Number of meals cooked with other fuels or stoves (not improved) per week	d	18.5	17.5	16	15
Ratio of capacity	c/(c+d)	0.119	0.167	0.238	0.286

Source: Gaia Association 2014; Geissler *et al.* 2013; Ethiopia, Ministry of Environment, Forest and Climate Change 2017.

4.24.6 Conclusions and recommendations

Synthesis of the findings

The first calculation of the ratio of capacity is based on the number of households using modern bioenergy cooking solutions compared to the estimated potential; this ratio reaches 48 per cent for biogas, assuming a potential based on number of current households with a biodigester, and 8 per cent for solid biomass.

The second calculation of the ratio of capacity is based on fuel and stove stacking. In the households with a biodigester, around 67 per cent of the meals are cooked with other cooking methods (firewood, charcoal, etc.). In the households already cooking with an improved cookstove, around 71 per cent of the meals are cooked with other cooking methods, mostly open fires. These two results illustrate the high potential to increase the use of the modern bioenergy solutions after the initial adoption by households.

However, fuel and stove stacking also positively contributes to the ratio of flexible capacity: households with biodigesters or improved cookstoves have the possibility to cook with other fuels and stoves if needed. This contributes to energy and cooking security. However, this flexibility hides the fact that the alternative solutions are often not modern bioenergy solutions, such as open fires.

Practices and policies to improve sustainability

The analysis raises the following question: Is fuel and stove stacking good or bad? It is usually considered bad when households use an improved cookstove and continue cooking with open fires for some food, because the indoor pollution remains high in this case. But at the same time, fuel and stove stacking gives flexibility to the households, and this is good: if there is a problem with the biodigester, for example, the household still can cook with another option. This gives some energy security to households. In other words, fuel and stove stacking is not necessarily bad, and clean cooking policies may want to promote primary and secondary clean cooking solutions rather than trying to promote only one primary cooking solution.

Future monitoring

Improving the availability of data on fuel and stove stacking is key for a good quality assessment of this indicator and for the definition of relevant clean cooking policies. It is essential to understand why households cook with different fuels and stoves in order to identify the clean cooking solutions better adapted to their needs and preferences.

4.24.7 References

Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P. (2013). *Biomass Energy Strategy of Ethiopia.* In cooperation with the Ethiopian Ministry of Water and Energy. Supported by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).

Gaia Association (2014). *Assessment of Cooking Energy in Households, Commercial Enterprises and Social Institutions in Ethiopia.*

Ministry of Environment, Forest and Climate Change (2017). *Dissemination of Improved Cook Stoves in Ethiopia.* Addis Ababa.

Ministry of Environment, Forest and Climate Change (2018). *National Forest Sector Development Program, Ethiopia. Volume I: Situation.* Addis Ababa.

Ministry of Water, Irrigation and Electricity (2018). *Report on National Biogas Users' Survey*, *2018*. National Biogas Programme of Ethiopia. Addis Ababa.

National Biogas Programme of Ethiopia (2015). *Report on Biogas Users' Survey.* Ministry of Water, Irrigation and Energy. Addis Ababa.

Rai, S. (2018). *National Biogas Programme of Ethiopia (NBPE)*. Addis Ababa.

Seyoum, S. (2018). *The Economics of a Biogas Digester*. Livestock Economics Division ILCA. Addis Ababa. https://core.ac.uk/download/pdf/132634928.pdf.

SNV Netherlands Development Organisation (2018). *Report on National Biogas Users' Survey, 2018.* National Biogas Programme of Ethiopia. Ministry of Water, Irrigation and Electricity. Addis Ababa.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Biogas pathway

Household-level biogas production was started a few decades ago in Ethiopia and is still considered to be in an infant stage. As of 2018 a total of 22,166 biodigesters had been built at the household level (Indicators 14 and 17), where cattle manure is used as the main feedstock. This distribution was achieved mainly through the financial and technical support of SNV-Ethiopia in collaboration with the National Biogas Programme of Ethiopia (NBPE). Unfortunately, this figure accounts for 0.63 per cent of the high scenario estimation of biogas production potential of the country, indicating that biogas production in Ethiopia is still far behind what it has to be.

Of the four sizes of biodigesters distributed by the NBPE, the predominantly used digester is the 6 m^3 one (89 per cent of all biodigesters). The use of the other three types of biodigesters for biogas generation is insignificant. The anaerobic digesters widely used in Ethiopia are the fixed-dome shaped digester and the float drum digester types. The fixed-dome digesters (68 per cent functioning) are better than the floating drum digesters (16 per cent functioning) from an operational perspective. At the country level, only 77 per cent of the installed biodigesters are operating (Indicator 17), possibly due to technical problems, water shortage, feed shortage, absence of management (abandonment) and lack of interest. The large distance to a water source is one of the root causes for those non-functional biogas digesters (Indicator 5).

From the currently operating biodigesters, households are producing around 17.6 million m^3 of biogas per year (Indicator 17). The produced biogas has been mainly used for household services such as cooking (>90 per cent) and lighting (~3.2 per cent) (Indicator 20). This replaces firewood used for cooking and kerosene used for lighting (Indicators 14 and 20) and increases the energy flexibility and security of households (Indicators 22 and 24). Despite its infant stage of development and the low number of biodigesters built in Ethiopia compared to other countries such as Vietnam (45,000 biodigesters), the attempts made so far have had significant socioeconomic and environmental implications in society.

The majority of the Ethiopian population resides in rural parts of the country and is dependent on traditional energy sources. Hence, the likelihood of the more vulnerable social groups (women and children) to be exposed to toxic gases from the combustion of traditional biomass is very high (Indicator 4). In Ethiopia, according to recent World Health Organization reports, every year 60,000 people lose their lives because of indoor air pollution, and 90 per cent of the incidences occur in children under five (Indicator 15).

Based on the survey done by SNV (2013), in Ethiopia, in comparison to solid fuel use, a significant portion of biogas users have indicated that they were fully satisfied with the benefits that biogas has brought them. Local air pollutants and greenhouse gas emissions per unit of useful energy from biogas are lower than in the reference case based on traditional biomass; they are also lower than in the case of solid biomass (Indicators 1 and 4). Therefore, the biogas digesters installed in Ethiopia have contributed greatly to the socioeconomic and public health of households and nearby communities.

Based on the existing number of biodigesters reported above, the amount of energy produced is estimated at 17.6 million of m^3 of biogas per year (387,865,060 MJ/yr) (Indicator 20). Considering that around 3.2 per cent is used for lighting, this is equivalent to 338,500 litres of kerosene, and it could represent $204,074 in annual savings from avoided kerosene purchases (Indicator 20). On the other hand, 412.5 thousand tons of firewood per year (Indicator 20) can be saved through the use of biogas as a means of energy for similar duties.

A reduction of expenditure for firewood (45 per cent) and charcoal (51 per cent) was reported for biogas users compared to non-biogas users (Indicator 11). Beyond the energy use of the biogas, the use of the digestate as a biofertilizer has also economic implications for households since it can replace chemical fertilizer. Considering the total number of biodigesters built, the bioslurry that remains is invaluable. Since the Ethiopian soil is characterized by low soil quality in a large part of the landmass (Indicator 2), and given the potential of biodigesters, a huge amount of digestate can be collected and used for soil quality amendment. This will improve the productivity of the soil and the quantity of crops harvested (Indicator 10). As a result the household income would be improved.

Construction of biogas digesters in the country has also generated demand for some skilled masons and technicians. More than 2,000 masons were trained by the National Biogas Programme in the country (Indicator 21). In addition, 2,800 formal jobs were reported as having been created as a result of biogas production; informal jobs are not included (Indicator 12). Having technical know-how of the field is crucial to obtain the expected benefits from biogas production.

The following barriers to the adoption of biogas and to its efficient production and use have been reported in Ethiopia: lack of coordination among institutions and stakeholders, inadequacy of highly skilled biogas technicians and workforce, weak private sector interest to invest in digester production or biogas production, limited awareness about biogas and digestate use in the society, open grazing of cattle and scattered dung rendering the collection of manure difficult, distance of water sources, and lack of economic and financial resources.

Finally, it can be concluded that implementation of the Global Bioenergy Partnership's sustainability indicators in Ethiopia helped in examining the development of the biogas sector. Calculations indicated that a significant amount of biogas is being produced in Ethiopia. Biogas may be a competitive option to replace traditional energy sources for cooking. However, the use of biogas technology is challenged by critical factors such as the cost of construction, amount of dung collected, free grazing of cattle causing dung collection difficult, and lack of awareness on the use of alternative feedstocks.

Hence, revising the biogas implementation strategy and crafting inclusive biogas policy is important. In particular, adopting different types of biogas digesters with reduced implementation cost, developing an integrated strategy on fodder and dung productivity, practicing stationary cattle rearing and awareness creation for diverse biogas feedstocks are essential. In effect, the shift from traditional energy sources for cooking to biogas technology helps to implement the key pillars set in the Sustainable Development Goals (SDGs).

5.1.2 Solid biomass pathway

In Ethiopia, similar to many other developing countries, solid biomass fuel is used by a large share (more than 92 per cent) of the population (Indicator 20). However, the biomass resources are still used in their most rudimentary, unmodified form, with very low technologies and efficiency of thermal conversion (Indicators 17 and 18). A significant share of rural and urban households still uses traditional and inefficient biomass and charcoal cookstoves, despite the encouraging success of the Ethiopian government in dissemination and adoption of improved cookstoves.

Around 65 per cent of the fuel wood is freely harvested from wet and dryland forests (Indicator 8). Around 35 per cent comes from trees on-farm, private woodlots, community forests and some from industrial plantations. Most of the freely harvested woody biomass originates from forest resources that are fragile shrublands, parklands and wildlife sanctuaries (Indicators 2, 7 and 8). High forests, on-farm trees, private and community woodlots, community and private plantations are also sources of biomass fuel. The woody biomass originating from the freely accessed and vulnerable resources supports the cooking energy needs of around 87 per cent of poor rural households. On the other hand, most of the solid biomass coming from on-farm trees, woodlots and community forests is supplied and sold to urban households.

The current productivity of woodlots and plantations is very low when compared to their potential. Specifically, the mean annual increment for industrial and woodlot plantation is around 12.5 m^3/ha/year and 15 m^3/ha/year respectively, with an overall national average mean annual increment of around 9.2 m^3/ha/year. In particular, the current estimated productivity of industrial plantations is low in comparison with the optimal growth (46 m^3/ha/year) for *Eucalyptus* stands, and growth of conifer (33 m^3/ha/year).

Consequently, the Ethiopian government developed and approved a 10-year (2017-2025) National Forest Sector Development Program (NFSDP) to narrow and eliminate the demand and supply gap not only in biomass fuel but also in other forest products by increasing utilization efficiencies and the establishment of sustainably managed trees and forest resources (Indicator 3). However, the current challenges of sustainable biomass resources supply remain tough and the outcomes of the NFSDP are yet to be seen and proved. Consequently, and in the short term, the severe exploitation pressure on shrublands and the illegal extraction of woody biomass from parklands and sanctuaries will continue strongly unabated, so as to meet the ever-widening demand and supply gap in fuel wood, charcoal and other alternative uses.

The high rate of rural poverty and the lack of strong means of income generation pressure rural livelihoods to depend more and more on the meager nearby natural resources, particularly free-access biomass. While the use of biomass fuel is justified to be strongly promoted, such free access, if not open access, to delicate ecosystems is very much prone to the “tragedy of commons”, with far-reaching catastrophic consequences for the country’s biodiversity.
The problems are further aggravated because most of the natural forests and parklands are owned by the local and federal governments. Constitutionally, the right to land ownership is an authority solely vested to the state, and citizens have only user rights, with no other legal claims (Indicator 9). Generally, land tenure and ownership are contentious issues in Ethiopia, being one of the root causes for the ongoing public upheaval and unrest. Allocation of new land area for bioenergy production is a formidable task that is yet to be introduced and reinforced in terms of adequate policies, implementation procedures and government priorities (Indicator 9).

The data related to the effects on the national food basket, changes in income and jobs associated with woody biomass cultivation, management and utilization are insufficient (Indicators 10, 11 and 12). However, given the country’s high rates of rural and urban youth unemployment, it is clear that the sector can play a decisive role in the creation and maintenance of job opportunities, provided that there is adequate land allocation for fuelwood tree cultivation; if there is also a strong sustainable management and utilization programme for woodland and shrublands. Assessments of Indicator 5 also support the possibility of irrigated cultivation of fuelwood trees owing to the country’s adequate endowment with renewable water resources. Promoting plantation development and sourcing the woody biomass from them enables reduction of professional injuries coming from wildlife and gender violence occurring during biomass collection from remote shrublands and woodlands (Indicator 16).

The traditional and inefficient process of converting woody biomass into charcoal generates high greenhouse gas and non-greenhouse gas toxic emissions (Indicators 1 and 4). The greenhouse gas emission per unit of useful energy produced by traditional biomass is 60 per cent higher than that of the biomass improved cookstoves, showing strong evidence for the need to enhance the government's improved cookstove programme (Indicator 1).

Production of charcoal using traditional earth-mound kilns incurs considerable losses, entailing five- to ten-fold as much energy input as would be required for direct burning of wood. The biomass conversion takes place in the open and in remote areas, polluting a wide expanse of land and threatening both human health (Indicator 16) and wildlife and biodiversity (Indicator 7). Biodiversity is impacted both in terms of resource depletion (Indicator 3) and increment of eco-toxicity. Large-scale use of traditional cookstoves has multi-dimensional and manifold impacts on resource use and productivity (Indicators 3, 8, 17 and 19), human health (Indicator 15) and biodiversity (Indicator 7) arising from the significant inefficiencies and excessive emissions.

Charcoal is predominantly produced, transported and marketed illegally. Illegality has hampered and diminished the contribution of charcoal in the creation of competent rural job opportunities (Indicator 12) and strong rural income generation (Indicator 11) for many pastoral, agro-pastoral and mixed farming households living in impoverished dry lowlands. It has further hampered the development of cost-effective and safe logistics for charcoal transport and distribution (Indicators 16 and 23). Marketing of woody biomass and charcoal in most regions of Ethiopia, as a result, relies on traveling wholesalers (single actors) who purchase loads of poles and charcoal directly from smallholders (roadside sales). In terms of flexibility, stove and fuel stacking, usual in households, contributes to a higher flexibility of the households; however, it also means that traditional biomass remains present in the household, and that the improved cookstove is not used for all meals (Indicator 24).

Several fatalities and impacts on human health are reported as outcomes of toxic emissions from the use of biomass burning at home, which renders household pollution. The toxic emissions particularly affect vulnerable members of households, including children under five years, and with complications lasting throughout adult life. This obligates prioritizing the reduction and elimination of toxic emissions, owing to the more than 92 per cent of population using biomass fuel on daily basis (Indicator 15). Nonetheless, solid biomass is a major income source for poor households in rural areas and is the primary source of fuel and construction in most urban areas of Ethiopia. For instance, charcoal incurs various costs like production, transport, taxation, bribes and payments to brokers, loading–unloading, and, in a few cases, payment for ownership rights etc. when it moves from the point of production through markets to consumers (Indicator 11).

In summary, although the current state of the solid biomass sector in Ethiopia is unsustainable, the country's high dependency on solid biomass might be an indicator of the need to focus on this resource as a potential energy and economic sector. Most of the biomass is coming from areas that either have low biomass productivity or are classified as nationally conserved forest areas and protected wildlife sanctuaries. On top of this, the biomass energy conversion technologies have low efficiency, and their application generates several toxic pollutants and an excess of greenhouse gas emissions.

Henceforth, the afforestation programmes should work aggressively to narrow the supply and demand for solid biomass. Moreover, developing an integrated strategy that focuses on the controlled use of exotic invasive species such as *Prosopis juliflora* and other potential woody biomass is essential. Because invasive species are causing ecological and economic problems, planning to utilize the resource in regulated way is critical. Consequently, the efforts made to use this biomass as an energy source would fix the ecological problem profoundly.

5.2 Recommendations and future monitoring for bioenergy pathways

Production and utilization of biogas and modern forms of solid biomass hold **many opportunities** for Ethiopia, including reduced reliance on fossil fuels, increased employment and other benefits. Yet, there are also downsides or important risks such as deforestation and degradation of soil quality. Implementing the GBEP Sustainability Indicators provides the possibility of monitoring the actual developments in this area and to take action if needed. The appropriate implementation of the GBEP sustainability programme enables the government to collect information on sustainability issues in the bioenergy sector, to analyze the information and use it for the design, development, steering and implementation of policies related to sustainable bioenergy production and utilization.

Quantifying, benchmarking, monitoring and improving the sustainability of bioenergy sources in Ethiopia is highly complicated. This is associated with the heterogeneity of the resource (which comes mostly from fragile ecosystems), the inconsistent source-to-market value chain, decisions made in the absence of reliable scientific data, the lack of a strong database, and the prevalent severe poverty conditions. These all are on top of the confounded situation with regard to the domain of the bioenergy sector.
Historically, bioenergy policies, programmes and projects (research and development) in Ethiopia have been administered inconsistently among multiple and different sectors such as rural development; water, irrigation and energy; agriculture and natural resources ministries that rendered ineffectiveness and inefficiency. As a matter of these, the probability and the realistic experience show the absence of an adequate level of communication and coordination between these sectors, which would create effective synergy and avoid duplication of efforts. Therefore, the first strategic issue that is strongly recommended to be addressed is the **establishment of a lasting institution and framework** for setting unified goals and national priorities, creating effective partnership and synergy, and maintaining smooth working communication among partners across sectors.

Regardless of the order of the procedure, once the problems of bioenergy institutional arrangements are fixed, the next step would be to work on the legal and policy domain of the sector. As an elucidatory example, devising strategies to access land resources for the sustainable production of biomass fuel feedstock (Indicators 8, 9 and 23) has to be dealt with within the Ethiopian political and economic framework. This task requires multi-sector (with the government) and multi-stakeholder engagement and amicable negotiation (Indicator 8). Hence, the **existing multi stakeholder working group (MSWG)** formulated at the federal and regional level need to be consolidated and strengthened by involving other relevant stakeholders such as academia and research institutions.

It is also strongly recommended to establish **a triple helix innovation** that should be created by concerned sectors (such as the Environment, Forest and Climate Change Commission; Ministry of Water, Electricity and Energy, Ministry of Agriculture; Ministry of Innovation and Technology), research institutes (the Ethiopian Environment and Forest Research Institute) and academia dealing with bioenergy and biorefinery (Science and Technology Universities, Institute of Technologies; Wondogenet College of Forestry and Natural Resources), bioenergy producing and processing communities and industries both in urban and rural areas.

The triple helix innovation provides a conducive environment to reinforce the effective driving forces helping to revolutionize the wasteful and traditional energy harnessed from biomass, for the improvement of the biomass and charcoal cookstoves. The outcome will be improvements in indicators 1, 3, 4, 15, 17 and 18. This will further simplify the assurance of sustainability of the biomass energy sector through an appropriate and innovative method of tracking and certification, which prompts the use of **blockchain technology**. Blockchain technology enables real-time authentication of the origin of biomass products, ownership of land resources, monitoring and follow-up, and it could improve many indicators (for example, 1, 3, 4, 8, 9 and 18).

Moreover, capacity development of both humans and institutions for sustainable biomass cultivation, management and utilization should be at the heart of the bioenergy programme of Ethiopia. In addition, it would help to carry out **periodic monitoring and evaluation** of the sustainability of the GBEP indicators. For most GBEP indicators tested in Ethiopia, secondary data sources were used. Additionally, a wider scope of primary data analysis on all indicators such as emission value, water quality value, actual prices of inputs, and other parameters of both bioenergy pathways for the future should be made through collection over wider geographic coverage and larger survey sizes.

The application of the indicators to **other bioenergy pathways**, such as liquid biofuels, would be also of interest. Currently in Ethiopia, there is no institution collecting bioenergy data for the implementation of the GBEP Sustainability Indicators program, and hence strengthening coordination among regional and national government's institutions will play a great role in the improvement of indicator implementation. An **Internet-based platform for bioenergy data collection** and handling would be useful to facilitate information sharing among regional and national bioenergy experts in the country.

Linking rural villages with decentralized modern biomass and other synergistic renewable energy investments (like solar, wind and mini-hydropower) is essential to reach the remote rural sector. For this purpose, building the capacities of collective actions, rural institutions and other stakeholders for decentralized renewable energy, particularly biomass energy, and awareness rising is critical. Enhancing public-private cooperation on modern renewable energy and promoting the dissemination of energy-saving technologies are important policy measures. Furthermore, developing energy infrastructure for modern biomass fuel generation is invaluable.

Creating conducive **investment opportunities** and businesses for private investors engaged in biomass fuel as well as identifying proper means of facilitating financial resources for decentralized biomass-based energy investments (e.g., linking with carbon financing) are also indispensable. Smoothening the market for renewable fuels and assuring the sustainability of supply and the adoption of appropriate renewable energy technologies is crucial. Policy measures should thus target technological innovation both from the demand perspective and from the supply side to ensure sustainable production and utilization of biomass resources that can cater to energy security.

Finally, bioenergy appliances are not locally available and are imported from abroad, raising the cost of bioenergy utilization, and they need to be produced locally and made available with lower prices. Similarly, efficient bioenergy conversion equipment should be made available. Digestate application technologies should be promoted for the replacement of inorganic fertilizers. The government has to keep subsidizing the cost of biogas production until the sector grows and is able to stand by itself. It is important to encourage the ongoing standardization effort of the Ethiopian government with regard to developing and issuing **national performance standards for cookstoves**. However, this effort alone is not adequate if it is not done in parallel with the creation of **effective regulatory enforcement** mechanisms.

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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