UN environment programme

SUSTAINABILITY OF BIOGAS AND SOLID BIOMASS VALUE CHAINS IN ETHIOPIA

Results and recommendations from implementation of the Global Bioenergy Partnership Indicators

SUMMARY

Ethiopian Environment and Forest Research Institute (EEFRI)
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ETHIOPIA

Supported by

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

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SUSTAINABILITY OF BIOGAS AND SOLID BIOMASS VALUE CHAINS IN ETHIOPIA

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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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1. OVERVIEW OF THE PROJECT

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 to 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 evolved out of a collaborative process. The indicators are a result of consensus among a broad range of national governments and international organizations on the sustainability of bioenergy. The emphasis is on providing measurements useful for informing national-level policy analysis and development.

The GBEP indicators are unique in that they can be applied to all forms of bioenergy. As such, the indicators do not feature directions, thresholds or limits and do not constitute a standard, nor are they legally binding on GBEP members. The indicators have been tested in 14 countries to date, ranging from industrialized countries such as Germany to those heavily dependent on biomass like Ethiopia and Kenya.

In Ethiopia, the project was implemented by the Environment, Forest and Climate Change Commission (EFCCC) and is anchored in the country's Climate Resilience Green Economy Strategy. The United Nations Environment Programme (UNEP) worked with the Commission to implement this project with support from the International Climate Initiative (IKI) of the German government. The calculation and analysis of the 24 indicators applied to the two priority pathways was conducted by the Ethiopian Environment and Forest Research Institute (EEFRI), with support from the EFCCC.

Based on collective consultation, two priority bioenergy pathways were selected:

1. Biogas produced from animal dung and used by households for cooking and heating; and
2. Solid biomass (charcoal, firewood) used in improved cookstoves for cooking and heating.

The national research team, with input from a multi-stakeholder working group, applied the 24 GBEP indicators to the above pathways. The results of this work are summarized in the following text. In-depth description of the national context and the calculation process for each indicator are detailed in the technical report, available online. https://bit.ly/2pq8kzV

This work is a starting point for increasing the sustainability of the bioenergy sector in Ethiopia. By establishing benchmarks, it is hoped that 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 about the direction of national bioenergy policies with the ultimate goal of achieving sustainability of the nation's bioenergy sector.

The GBEP activities are managed by the GBEP Secretariat, housed at the Food and Agriculture Organization of the United Nations.

2. COUNTRY CONTEXT

A FEW NUMBERS

Ethiopia is considered one of the largest and most densely populated countries in Africa. The country is home to around 108 million people, and around 21 per cent of the population was urban in 2018. The gross domestic product (GDP) totalled $52 billion (in 2010 dollars) in 2016, and 24 per cent of the population lived beneath the national poverty line that year.

The major environmental issues facing Ethiopia include frequently occurring drought, flooding, soil erosion, deforestation and depletion of soil nutrients. Because of the heavy reliance of the economy on rain-fed agricultural and pastoral activities, the country is vulnerable to severe food shortages and famines.

The final energy consumption of Ethiopia was an estimated 42 million tons of oil equivalent in 2016, of which around 92 per cent is consumed by the residential sector. Biomass energy sources account for 91 per cent of final energy consumption and for 98 per cent of energy consumption in the residential sector. Electricity access reaches 87 per cent of the urban population and around 5 per cent of the rural population. Due to the country's population pressure and rapid economic growth, the demand for energy is increasing tremendously and could grow by as much as 10-14 per cent annually until 2037.

SOME KEY POLICIES

The Growth and Transformation Plan (GTP) is a national five-year plan of the Ethiopian government. The major objective of the second five-year plan (GTP II), from 2025 to 2020, is to serve "*as a springboard towards realizing the national vision of becoming a low middle-income country by 2025, through sustaining the rapid, broad based and inclusive economic growth*".

The GTP's targets include the distribution of more than 11 million improved cookstoves, 31,400 improved biogas systems and 20,000 household biofuel stoves, as well as the afforestation of 2 million hectares and the reforestation of 1 million hectares by 2030. The plan also targets the development of more than 500,000 hectares of land for biofuel plantation, to produce 1.4 million litres of bioethanol and 450 million litres of biodiesel.

Ethiopia has also issued several policy and strategic documents aimed at ensuring attainment of the Sustainable Development Goals. Foremost are the Climate Resilient Green Economy Strategy for addressing both climate change adaptation and mitigation objectives, Ethiopia's National Energy Policy and the Biomass Energy Strategy.

3. BIOGAS AND SOLID BIOMASS: TWO PRIORITY BIOENERGY PATHWAYS

BIOGAS PRODUCED FROM ANIMAL DUNG AND USED BY HOUSEHOLDS FOR COOKING AND HEATING

Ethiopia has a large livestock population. Although the cattle population is mostly range fed, around 40 per cent of the dung is accessible. Biogas production from agricultural residues is not yet popular in the country.

The National Biogas Programme of Ethiopia (NBPE) was launched in 2008, and a total of 22,166 biodigesters have been distributed by 2018, an estimated 77 per cent of which are functioning. The most frequently distributed biodigester is the 6 cubic metre (m^3) SINIDU biodigester. The government wants to expand the production and use of biogas in the country, and the new biogas programme (NBPE+) has an objective of 35,000 installed biodigesters by 2020.

Biogas users acknowledge the benefits of biodigesters, such as time savings for cooking and wood collection, reductions in smoke and household air pollution, and the high value of the bioslurry. However, most users have continued to use wood, dung or charcoal even after installation of the biodigester. This is known as fuel and stove stacking: households cook with different fuels interchangeably in case of shortage of biogas or because of preferences for some meals.

A significant challenge of the biodigester programme is water scarcity and drought during certain times of the year in many areas of Ethiopia.

SOLID BIOMASS (CHARCOAL, FIREWOOD) USED IN IMPROVED COOKSTOVES FOR COOKING AND HEATING

Ethiopia has close to 17.4 million hectares (15.7 per cent of the country area) of forest resources, including bamboo, dense woodland, natural forests and planted forests. The annual volume of wood harvested for wood fuel was around 120 million m^3 of roundwood equivalent in 2015 (115 million m^3 as firewood and 5.4 million m^3 for conversion into charcoal). The sustainable supply of wood fuel from natural forests and woodlands is only 32.1 million m^3 of roundwood equivalent.

The Ethiopian government established the National Improved Cookstoves Program in 2013. The programme is scheduled to run to 2030, with five-year phases aligned with the government's Growth and Transformation Plan.

An estimated 11 million improved cookstoves had been distributed in Ethiopia by 2017. The most common stove models are Mirt and Gonzie (for injera baking) and Tikikil and Lakech (for non-baking services). The last two are more efficient stoves but are not yet used by many households. The first two are not seen as sufficiently efficient (less than 25 percent) to be considered improved cookstoves.

4. KEY FINDINGS FROM THE 24 INDICATORS

INDICATOR 1. LIFE CYCLE GREENHOUSE GAS EMISSIONS

RESEARCHERS

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DEFINITION

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

MEASUREMENT UNIT(S)

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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The spreadsheet-based life cycle analysis tool, developed by the Institut für Energie-und Umweltforschung Heidelberg in partnership with the Global Bioenergy Partnership and UNEP was used to quantify the carbon dioxide, methane and nitrous oxide emissions of each stage of the value chain.
- Emission factors are based on international literature and life cycle analysis databases and adapted to Ethiopia.
- In the case of biogas, the scope of the life cycle analysis of greenhouse gas emissions covered collection of the animals' excreta, anaerobic digestion and use of biogas for cooking. It does not include the emissions associated with the bioslurry. Emissions of the biogas pathway are compared to those of a pathway based on traditional biomass (open fires).
- In the case of solid biomass, the scope of the life cycle analysis of greenhouse gas emissions covered transport of wood and charcoal, kilns and use of charcoal for cooking. Emissions of the solid biomass pathway are compared to those of a pathway based on traditional biomass (open fires).

KEY FINDINGS

Table 1.1. Results of the life cycle analysis of greenhouse gas emissions

	Biogas	Firewood in improved cookstove	Charcoal in improved cookstove
Greenhouse gas emissions (gCO_{2EQ}. per MJ heat energy)	12	62	130
Main source of greenhouse gas emission	Leakage from the biodigester (90%)	Stove (95%)	Charcoal processing (82%)
Reference for comparison	Traditional cooking with firewood and open fires	Traditional cooking with firewood and open fires	Traditional cooking with firewood and open fires
Difference over reference	-95%	-73%	-47%
Main factors behind the difference	Burning is more complete with biogas than with firewood.	Improved cookstoves are more efficient than open fires. With more efficient combustion, less firewood is needed.	Charcoal improved cookstoves are more efficient than open fires. However, charcoal production has high emissions.

KEY MESSAGES

Biogas

- Minimizing the leakage of greenhouse gases from the biodigester deserves attention.
- The use of biogas from manure has good potential to offset the greenhouse gas emissions from enteric fermentation. Moreover, it reduces the use of chemical fertilizers, which are also greenhouse gas contributors. This should be better assessed.

Solid biomass

- Innovation in improved cookstoves for firewood and charcoal is key to improve the efficiency of combustion and therefore reduce greenhouse gas emissions.
- The development, introduction and adoption of improved charcoal-making kilns must be promoted.
- Blockchain technology deserves exploration to track and thus prove the legality and sustainability of firewood and charcoal manufacturing. This could be part of the ongoing programme of the Ministry of Innovation and Technology of Ethiopia on testing blockchain in tracking and certifying agri-products.
- Better knowledge on the transport of firewood and of charcoal and on the efficiency of the cookstoves in real conditions would be useful to better estimate the associated greenhouse gas emissions.
- Biomass burning is considered to emit zero biogenic carbon dioxide, assuming that the wood would grow again and that there is no land-use change induced by the growing 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.

MORE IN THE TECHNICAL REPORT

- Detailed assumptions behind the computation.
- Emissions for each stage of the life cycle.
- Comparison of the emissions of the pathways with liquefied petroleum gas.
- Synthesis figures and tables.

INDICATOR 2. SOIL QUALITY

RESEARCHERS

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DEFINITION

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

MEASUREMENT UNIT(S)S

Percentage

OVERALL METHODOLOGY OF THE IMPLEMENTATION

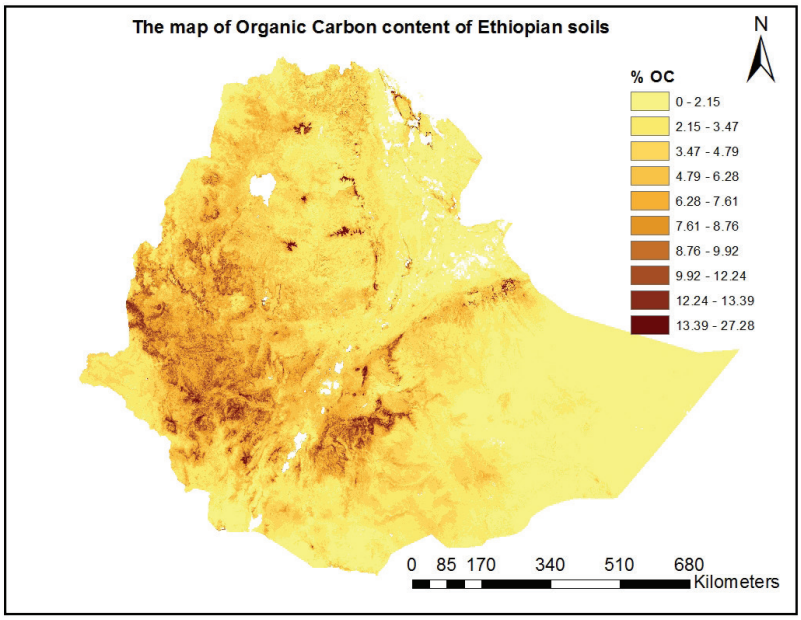
- Various soil quality indicators are used to evaluate different land use types: soil organic carbon, total nitrogen and soil acidity (pH).
- The analysis was made at a national level rather than based on the selected bioenergy pathways. Secondary sources from existing international and national studies were used.

KEY FINDINGS

National level

- Ethiopian soils are undergoing severe mining of nutrients because of rapid population growth combined with land shortage. Expansion to marginal lands and protected areas has become a common practice.
- Eighteen major soil types are found in Ethiopia. More than 82 per cent of the soils are Leptosols (24 per cent), Vertisols, Nitisols, Gypsisols, Calcisols and Cambisols. Soil types of woodland ecosystems, which is the major source of fuel wood and charcoal, vary depending on the location and altitude.
- More than 50 per cent of Ethiopian soils are acidic.
- Average soil organic carbon is 2.7 per cent (Amhara), 3.7 per cent (Oromia), 3.9 per cent (Tigrai) and 4.4 per cent (Southern Nations, Nationalities, and Peoples' Region). This is adequate – forested regions in the central, southern and south-western parts of the country exhibit distinctively larger values of organic carbon than those of other regions.
- 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.
- Reduced soil nitrogen can follow tree harvesting, while there is a risk of soil acidification due to harvesting of boles, branches and leaves, particularly in nutrient-poor sites.
- Some initiatives are ongoing, such as trials on farmers' fields by SNV Ethiopia and LCB/Institute for Sustainable Development, and greening of the Butajira municipality by collecting bioslurry from households.

Figure 2.1. Map of organic carbon content in topsoil (0-5 centimetres) of Ethiopia



Source: FAO *et al*. 2012

KEY MESSAGES

National level

- More work is necessary to complete national maps concerning high-potential solid biomass areas.
- Since agroecologies and soil types found in the country are different from place to place, generalizations are difficult. Therefore, it is pertinent to identify site-specific indicators of soil quality that can be used as a reference on the impact of biomass utilization on specific soil quality parameters.
- Soil quality indicators, such as organic matter content, total nitrogen and pH, can be used effectively in sustainable forest management only if threshold values are identified Therefore, it is important to create soil organic carbon, total nitrogen and pH databases and to set threshold values on representative forest types using standard and uniform soil sampling methodologies that are simple and cost effective to measure, and applicable to the majority of forest ecosystems.

Biogas

- Manure or digestate, whether alone or in mixture with compost, has potential as an effective soil amendment for restoration of degraded lands and forests to forestry end use. 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 to package it for sale and use as a source of fertilizer. But it is very possible to use the slurry at the plant premises.
- There is a need to compile the existing local technologies and other countries' experiences to scale up technologies for bioslurry use in forestry development; it is especially applicable for tree seedling production in a nursery.

Solid biomass

- The soil quality can be improved through sustainable forest management or sustainable community-managed woodlot plantations and agroforestry.

MORE IN THE TECHNICAL REPORT

- Description of the 18 soil types in Ethiopia.
- Quantified soil properties like pH, cation exchange capacity, color and total nitrogen, for the major types of vegetation in Ethiopia.
- Identification of available studies.
- Maps.

INDICATOR 3. HARVEST LEVELS OF WOOD RESOURCES

RESEARCHERS

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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.

MEASUREMENT UNIT(S)

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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The indicator focuses on wood and forest resources at the national level.
- Secondary data sources (scientific publications, reports, survey results, national figures, etc.) were used.

KEY FINDINGS

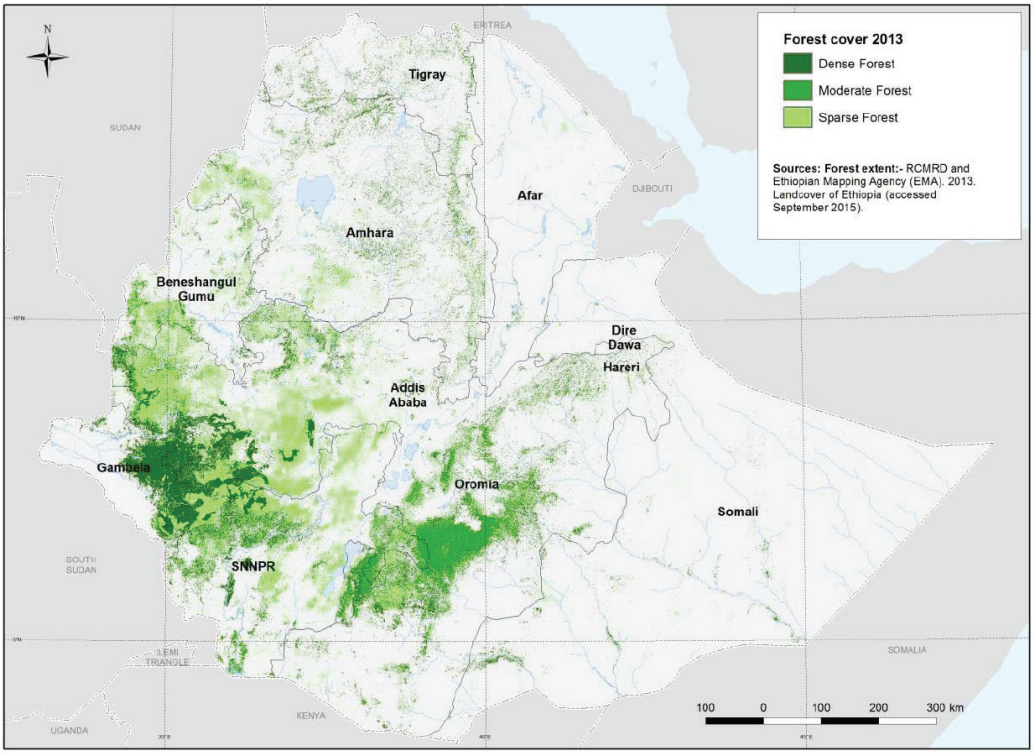
Biogas

- According to biogas users and experts, the use of biogas for cooking has greatly reduced the use of firewood in Ethiopia, contributing to improvement in the forest coverage. This is, however, not quantified.
- The introduction of biogas technology has strengthened area closure because the users of the technology have changed their free grazing to a cut-and-carry animal feeding system.

Solid biomass

- According to the Ethiopian definition of forest, the forest coverage of Ethiopia is estimated at around 17.4 million hectares or 15.5 per cent of the country's land mass (Figure 3.1). Woodlands represent 9.5 per cent of the territory, and natural forests 4.7 per cent.
- Actual incremental yield for the various types of forest vegetation is very low (Table 3.1). Reasons are over-logging, lack of proper management, and lack of proper silviculture and stand management. Moreover, the current industrial plantations are not located on good sites.
- The annual volume of wood harvested for wood fuel was approximately 120 million m^3 of roundwood equivalent in 2015 (115 million m^3 as firewood and 5.4 million m^3 for conversion into charcoal). This is more than 92 per cent of the total roundwood equivalent produced in the country.
- 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.

Figure 3.1. Distribution of the forest resources of Ethiopia



Source: EMA 2013 cited in MEFCC 2018a

Table 3.1. Growth and standing stock of forests in Ethiopia

	Forest vegetation		
	Natural forest (excludes bamboo)	**Plantation (industrial)**	**Plantation (woodlots)**
Standing stock (m^3/ha)	49	179	75
Total standing volume (m^3)	790 355 000	33 836 907	61 129 275
Mean annual increment (MAI) (m^3/ha/year)	2.0	12.5	15.0
Annual sustainable yield (m^3/year)	32 594 000	Not available	Not available

Source: WBISPP 2004 and FSR 2015, cited in MEFCC 2018a

KEY MESSAGES

National level

- 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*, etc.
- Identifying which multi-purpose tree species are most appropriate for which agroecological zone is needed to promote and develop sound management and agroforestry practices. Land holders will have to be informed and trained on this.
- The strategy proposed in 2018 by the ex-Ministry of Environment, Forest and Climate Change, now Environment, Forest and Climate Change Commission, for improved and sustainable charcoal production must be implemented.
- Non-wood energy alternatives, including biogas, must be promoted.
- More-specific data on the harvest levels of wood resources for energy purposes are needed, including the source of wood supply and the harvest per hectare.
- These details will contribute to assessing whether statistics on the use of wood fuel match the shares of energy coming from traditional use of biomass.

MORE IN THE TECHNICAL REPORT

- Ethiopian definition of forest and the difference from the definition of the Food and Agriculture Organization of the United Nations (FAO).
- Tree cover losses and gains per region of Ethiopia.
- Expected projection of wood fuel demand.
- Details on the Ethiopian forest policy and strategy (2007) and on the recent forest proclamation number 1076/2018.

INDICATOR 4. EMISSIONS OF NON-GREENHOUSE GAS AIR POLLUTANTS, INCLUDING AIR TOXICS

RESEARCHER

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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.

MEASUREMENT UNIT(S)

Emissions of particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_X), sulphur dioxide (SO_2) 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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The spreadsheet-based life cycle analysis tool, developed by the Institut für Energie-und Umweltforschung Heidelberg in partnership with the Global Bioenergy Partnership and UNEP, was used to quantify the emissions of sulphur dioxide, nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, PM_{10}, dust and ammonia at each stage of the value chain.
- Emission factors are based on international literature and life cycle analysis databases and adapted to Ethiopia.
- In the case of biogas, the scope of the life cycle analysis of non-greenhouse gas emissions covered collection of the animals' excreta, anaerobic digestion and use of biogas for cooking. It does not include the emissions associated with the bioslurry. Emissions of the biogas pathway are compared to those of a pathway based on traditional biomass (open fires).

- In the case of solid biomass, the scope of the life cycle analysis of non-greenhouse gas emissions covered transport of wood and charcoal, kilns and use of charcoal for cooking. Emissions of the solid biomass pathway are compared to those of a pathway based on traditional biomass (open fires).

KEY FINDINGS

- Biogas emits significantly more sulphur dioxide and nitrogen oxides compared with firewood and charcoal used in improved cookstoves. The sulphur dioxide result is explained by the sulphur content of biogas due to the fermentation process and the sulphur content of the substrate. Nitrogen oxide emissions are related to the temperature level of the combustion, which is higher with biogas than with wood, and the azote content of manure and therefore of biogas.
- The use of biogas also emits much less particulate PM_{10} than firewood and charcoal used in improved cookstoves. This is particularly important to reduce household air pollution and its impacts, as described in Indicator 15.
- The use of biogas emits less carbon monoxide than firewood and charcoal burned in open fires and improved cookstoves. This is important, since carbon monoxide is a lethal gas.

KEY MESSAGES

- Biodigester improvement could reduce non-greenhouse gas emissions.
- Biomass stove innovation is essential to reduce household air pollution. However, improvement in charcoal production is also essential. Charcoal bans are not necessarily a relevant option in the short term since this contributes to the absence of improvement in charcoal production processes.
- This indicator must be closely linked to Indicator 15 on the negative effects of household air pollution.
- The inclusion of the smaller particulates ($PM_{2.5}$) in the life cycle analysis tool used would be an important addition, given the toxicity of these particles for health.
- The scope of the indicator could be extended to the impacts of the gases.

MORE IN THE TECHNICAL REPORT

- Detailed assumptions behind the computation.
- Emissions of each stage of the life cycle.
- Comparison with liquefied petroleum gas.
- Synthetic figures and tables.

INDICATOR 5. WATER USE AND EFFICIENCY

RESEARCHERS

Mahelete Tsegaye and Dr. Yonas Yohannes
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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, and

(5.1b.) as the percentage of total annual water withdrawals, 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.

MEASUREMENT UNIT(S)

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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Water resources at the national level were estimated using FAO AQUASTAT.
- Water consumption was based on national reports.

KEY FINDINGS

National level

- The surface water resource potential is impressive. Ethiopia has 12 major river basins, which form four major drainage systems.
- External water resources are null, and the surface water leaving the country is estimated at 96,500 million m³/year. These important run-off flows to other countries have resulted in Ethiopia being called the "Water Tower of East Africa".
- The groundwater potential of the country is not known with certainty. Groundwater is used mostly for drinking supply.
- Agriculture is by far the main water-withdrawing sector (85 per cent of total withdrawal).

Biogas

- Availability of sufficient water is a key factor limiting the pace of biogas expansion in Ethiopia.

Table 5.1. Water withdrawal in Ethiopia

Parameter	Year	Value	Unit
Total water withdrawal	2016	10 548	million m³/year
Irrigation	2016	9 000	million m³/year
Livestock	2010	687	million m³/year
Municipalities	2005	810	million m³/year
Industry	2005	51	million m³/year
Per inhabitant	2015	106	m³/year
As % of total renewable water resources	2016	8.6	%

Table 5.2. Water withdrawals associated with biogas production in Ethiopia in 2016

Parameter	Value
Total actual renewable water resource in Ethiopia	122 000 million m³/year
Number of working biogas digesters	22166
Water requirements for operating biogas digesters (6 m³ digesters)	
Total	273 057 m³/year
Share of total actual renewable water resource	2.24%
Per unit of energy output	0.0017 m³/MJ

Solid biomass

- Plantations of wood are mostly rain fed in Ethiopia. Water consumption for solid biomass cultivation is composed mainly of green water.

KEY MESSAGES

Biogas

- The availability of water and the possibility to use other water sources for the installed and future biodigesters are essential. Urine is a possibility; however, its use requires the construction of a simple floor for the collection of urine and its injection into the biogas plant.
- Better monitoring of the biodigesters after their installation would contribute to better use of the digesters, including reducing the difficulties associated with water access, if any.

MORE IN THE TECHNICAL REPORT

- Description of the four major drainage systems of Ethiopia.
- Run-off flows from Ethiopia to other countries.
- Water withdrawals per sector.
- Maps.

INDICATOR 6. WATER QUALITY

RESEARCHERS

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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.

MEASUREMENT UNIT(S)

(6.1) Annual nitrogen and phosphorus loadings from fertilizer and pesticide active ingredient loading attributable to bioenergy feedstock production (per watershed area): in kg of nitrogen, phosphorous and active ingredient per hectare per year;

(6.2) Pollutant loadings attributable to bioenergy processing effluent: pollutant levels in bioenergy processing effluent in mg/litre

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Secondary data were used.
- Quantification of the indicator was not fully possible due to a lack of data.

KEY FINDINGS

National level

- Water pollution is still limited to industrial, mining and urban areas. It is a growing problem in the Awash river basin, due to major cities and industries in the upper basin.
- Salinity problems due to water logging were observed in irrigated lands along the Awash River.

Biogas

- Pathogenic organisms are removed in the process of anaerobic digestion taking place in the biogas digester. Moreover, bioslurry has many benefits (fertilizer, insect repellent, concentrated feed, etc.).
- More than 90 per cent of the households with a biodigester use bioslurry as fertilizer. However, this varies by region. In more urbanized regions like Butajira and Bishoftu towns, bioslurry was mostly discarded to wastelands. The resulting pollution issues were not assessed.
- 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. However, empirical data on the management of the bioslurry/digestate are missing to reach a strong conclusion.

Solid biomass

- This indicator does not apply to solid biomass, since no fertilizer is used to grow solid biomass for energy purposes in the country.

KEY MESSAGES

Biogas

- Informing and training farmers on the multiple benefits of bioslurry is needed. This will contribute to better use of the bioslurry.
- Better characterization of the composition of bioslurry from biodigesters, and water quality assessment of water bodies receiving these effluents directly, are needed.

MORE IN THE TECHNICAL REPORT

- Information on erosion and sedimentation.
- Prospects for agriculture water management.
- A longer list of the benefits of the bioslurry.

INDICATOR 7. BIOLOGICAL DIVERSITY IN THE LANDSCAPE

RESEARCHERS

Getachew Kebede and Adefires Worku
Ethiopian Environment and Forest Research Institute (EEFRI), Addis Ababa, Ethiopia

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.

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 were 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.

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 were used.

KEY FINDINGS

National level

- Ethiopia is a biodiversity hotspot country. It ranks 5th in the region and 25th in the world in terms of biodiversity.
- Ethiopia has demarcated different biodiversity hotspot areas: national parks, controlled hunting areas, sanctuaries and wildlife reserves. Biodiversity hotspots and protected areas share a total surface area of 30 361 km^2, or 2.69 per cent of the total area of the country.
- Thirty-seven invasive alien species and several native bush encroachers are identified. Some of them grow in high-ecosystem-value areas (for example, *Prosopis juliflora* in the protected areas of the Afar region, displacing several indigenous plant and animal species).

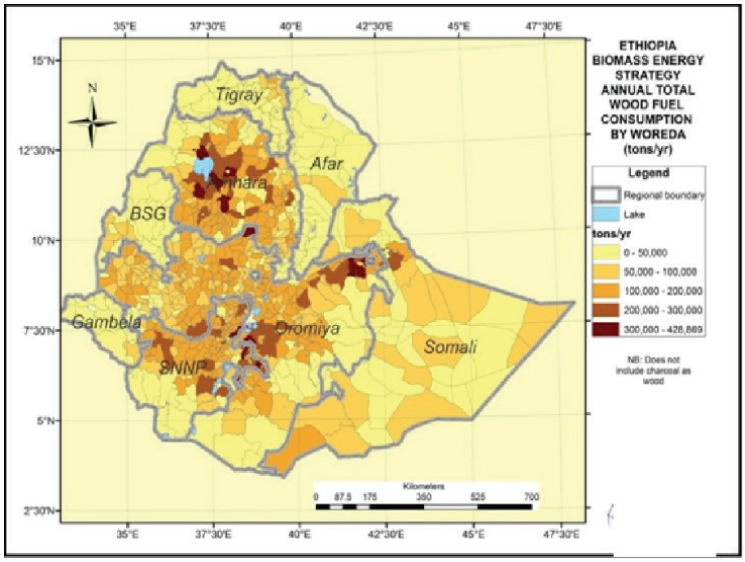
Biogas

- By reducing the use of wood fuel, biodigesters help to avoid the loss of biological diversity.

Solid biomass

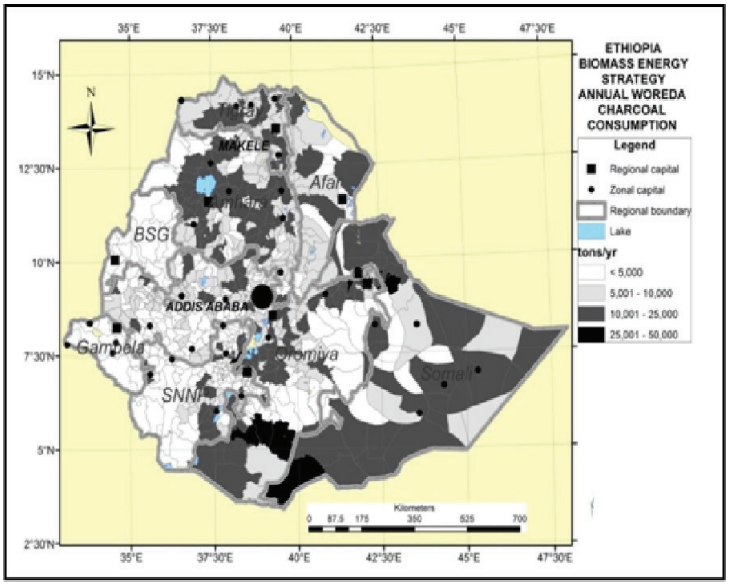
- Large volumes of wood fuel are used in protected regions, such as east of Lake Tana in the Amhara region, the Hareghe highlands, and on either side of the Rift Valley in the Southern Nations, Nationalities, and Peoples' Region and the Oromia region.
- Controlled hunting areas in Ethiopia are the most vulnerable to wood fuel collection.
- The use of invasive species for charcoal is increasing, particularly with *Prosopis*.

Figure 7.1. Wood fuel consumption in Ethiopia, by woreda



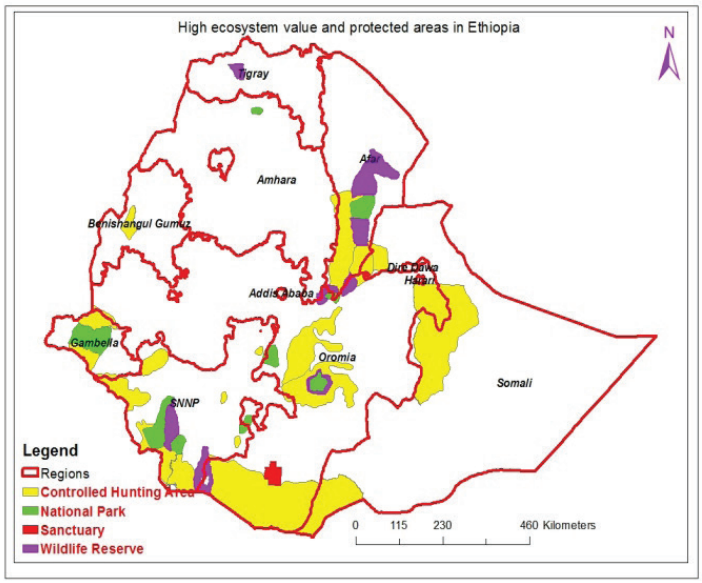
Source: EBES 2013

Figure 7.2. Charcoal production in Ethiopia



Source: EBES 2013

Figure 7.3. Hotspot ecosystem areas in Ethiopia



Source: EBES 2013

KEY MESSAGES

National level

- The use of more efficient cookstoves, biogas, cattle dung and crop residues is essential to reduce the pressure on forests from accessing wood fuel, and thus to lower the risks of losing biological diversity.
- The efficient and well-designed use of invasive species needs to be promoted to minimize the effects of invasive species on biodiversity hotspots.
- The establishment of a strong monitoring system is needed to identify the zones with higher risks.

MORE IN THE TECHNICAL REPORT

- List of the biodiversity hotspots in Ethiopia.
- Details on invasive species and on governmental plans to reduce them.
- Maps illustrating the overlap between protected areas, charcoal and firewood consumption.
- Wood fuel and charcoal consumption in controlled hunting areas, national parks, sanctuaries and wildlife reserves.

INDICATOR 8. LAND USE AND LAND-USE CHANGE RELATED TO BIOENERGY FEEDSTOCK PRODUCTION

RESEARCHERS

Getachew Kebede and Dr. Tatek Dejene
Ethiopian Environment and Forest Research Institute (EEFRI), Addis Ababa, Ethiopia

DEFINITION

(8.1) Total area of land for bioenergy feedstock production, and as compared to total national surface and (8.2) agricultural land and managed forest area;

(8.3) Percentages of bioenergy from: (8.3a) yield increases, (8.3b) residues, (8.3c) wastes, (8.3d) degraded or contaminated land;

(8.4) Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production, including the following (among others):

- arable land and permanent crops, permanent meadows and pastures, and managed forests

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

MEASUREMENT UNIT(S)

(8.1 and 8.2) hectares and percentages (8.3) percentages (8.4) hectares per year

OVERALL METHODOLOGY OF THE IMPLEMENTATION

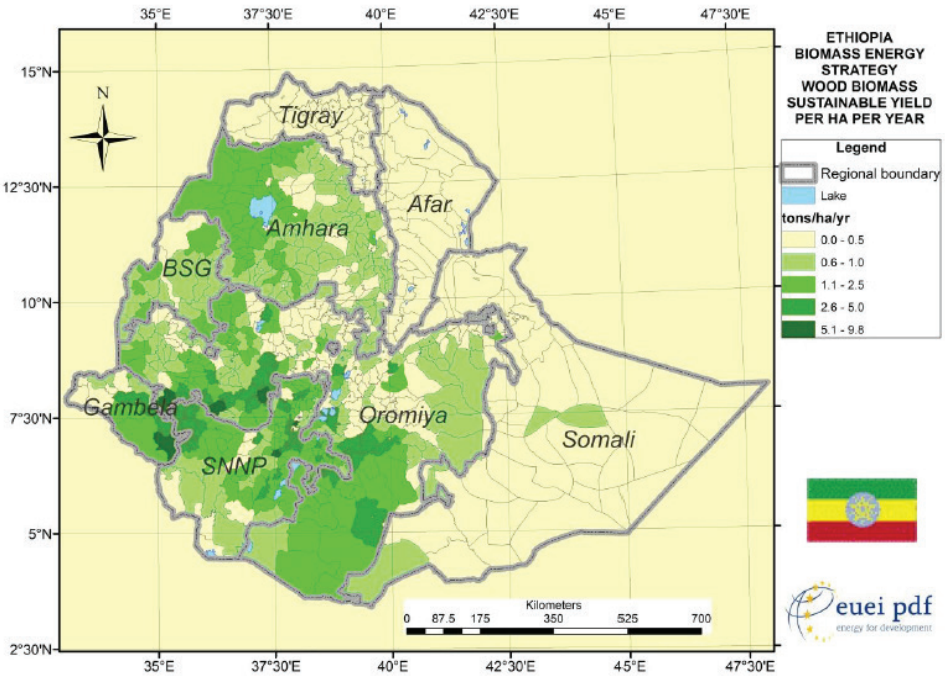
- Secondary data were used – based, among others, on satellite data produced by the Catholic University of Louvain-Geomatics and the European Spatial Agency.

KEY FINDINGS

National level

- According to the forest definition of the FAO, forest and woodland represented 15 million hectares (13 per cent of the land) and 45 million hectares, respectively, in 1990, and 12.5 million hectares (11 per cent of the land) and 41 million hectares, respectively, in 2015.
- The estimated annual forest loss was 104,900 hectares between 1995 and 2015. The losses were even worse until 2010 (141 000 hectares lost per year since 1990), slightly compensated by an annual increase of 40 600 hectares between 2010 and 2015.
- The causes of these changes are demand for wood products, farmland expansion, grazing land expansion (green fodder is the major type of feed and its share largely increased between 2000 and 2015) and fires. However, the respective contributions to land use are not well quantified.

Figure 8.1. Annual natural sustainable supply of woody biomass in Ethiopia, by woreda (tons/ha/yr)



Source: EBES 2013

Solid biomass

- Total national consumption of wood for energy purposes (including wood for charcoal) was an estimated 105.2 million tons in 2013, out of a total of 196 million tons. It includes 28.6 million tons of wood to produce 5.7 million tons of charcoal.
- Total consumption of residues and dung is 19.7 million tons and 22.8 million tons per year, respectively. Regional shares of wood consumption are 37 per cent in Oromiya, 25 per cent in the Southern Nations, Nationalities, and Peoples' Region, and 23 per cent in Amhara.
- Plantation forests are dominated by *Eucalyptus*, *Cupressus*, *Pinus* and *Acacia* genera. The total area of planted forests is estimated at 972,000 hectares, including 754,900 hectares of non-industrial plantations, including energy uses (less than 1 per cent of the nation's surface area, and 6 per cent of total forest area).
- Bioenergy from degraded or contaminated land was not found.

KEY MESSAGES

National level

- The establishment of a continued land cover monitoring system, with detailed information on the uses of the wood, is crucial to have an up-to-date and accurate view of trends in land-use change. Primary data from such a monitoring system could then be combined with the results of household surveys.

MORE IN THE TECHNICAL REPORT

- Land cover types in Ethiopia, including shares and changes between 2000 and 2015.
- Distribution of forest and plantations in the country.
- Linkages between animal feed and land-use change.
- Consumption of different types of biomass fuels by region.
- Evolution of wood removal from forest.

INDICATOR 9. ALLOCATION AND TENURE OF LAND FOR NEW BIOENERGY PRODUCTION

RESEARCHERS

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DEFINITION

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

MEASUREMENT UNIT(S)

Percentage

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Quantitative measurement of the indicator was not possible due to shortage of data. An in-depth review of relevant secondary sources was carried out on land legislative frameworks related to land tenure and access to and conflicts on land associated with new bioenergy production.
- A concise description was made of legal systems linked to land tenure, ownership and use related to solid biomass and biogas production.

KEY FINDINGS

National level

- Land tenure 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.
- 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 2007 forestry policy allows for forests to be designated as either private, state, community or association owned. The type of property right for 85 per cent of the population is usufructuary right (private user-rights) on public land.

- Securing land involves the concurrence of public authorities at several levels: local (kebele or woreda), regional or national.
- Small land holdings with subsistence production dominate the farming system. The average land holding of farmers is estimated at around 0.5 hectares and is reportedly diminishing with continued population growth and the accompanying redistribution of land.
- Sustainable land management is under development on 390,000 hectares of degraded land.

Biogas

- The construction of biodigesters does not require much space (around 16 square metres for the 6 m^3 biodigester).

Solid biomass

- The government of Ethiopia has allocated some plantations for community management, and several incentives for plantation development are proposed (free supply of seedlings, lease-free land, tax removal, support to get loans from banks, etc.).

KEY MESSAGES

National level

- Policy and legal reform should ensure security of land tenure for smallholder farmers and rural communities.
- Monitoring of the effect of land tenure and access on the sustainability of bioenergy is needed. A broad sample of households in all regions should be surveyed.
- In addition, better coordination and collaboration would be needed between the related competent governmental agencies and ministries, which can provide the needed information to measure this indicator.

MORE IN THE TECHNICAL REPORT

- Historical development of land tenure in Ethiopia.
- Detailed description of the current land tenure system and the legal procedures for acquiring land.
- Leased prices.
- Different types of incentives for plantation development.

INDICATOR 10. PRICE AND SUPPLY OF A NATIONAL FOOD BASKET

RESEARCHERS

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DEFINITION

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

- Changes in demand for foodstuffs 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.

MEASUREMENT UNIT(S)

Tons; US dollars; national currency (Ethiopian Birr); percentage

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- This indicator is particularly important in the case of bioenergy based on crop production. It is less important in the case of biogas and solid biomass as selected in Ethiopia.
- However, some reflections are proposed in the case of biogas, and particularly on how the bioslurry generated by biodigesters could have an impact on the price of the food basket of households.
- Secondary data were used, including various national datasets and reports, as well as surveys conducted on the national biogas programme in 2015 and 2018.

KEY FINDINGS

Biogas

- The expenses for chemical fertilizer used by households were reduced by 35 per cent thanks to the use of bioslurry. In other words, the total costs of obtaining the main elements of the food basket are reduced.
- Most households use the slurry for garden vegetables such as onions, tomatoes, peppers and potatoes, or for maize.
- An interesting side effect of the biodigester was an increase in the number of animals (33 per cent of respondents) in order to produce more dung.

Table 10.1. 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: NBPE 2015; SNV 2018

KEY MESSAGES

National level

- Assessment of 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.

Biogas

- Stronger policies to promote biodigesters would tackle several issues at the same time, such as energy access but also reduction in the use of chemical fertilizer and therefore in the cost of the food basket.

MORE IN THE TECHNICAL REPORT

- Description of the components of the food basket.
- Description of the uses of bioslurry by region of Ethiopia.
- Changes in crops grown after the use of bioslurry.

INDICATOR 11. CHANGE IN INCOME

RESEARCHERS

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DEFINITION

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

(11.1) Wages paid for employment in the bioenergy sector in relation to comparable sectors;

(11.2) Net income from the sale, barter and/or own consumption of bioenergy products, including feedstocks, by self-employed households/individuals.

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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- In addition to analysis of the wages, a special focus was on assessment of the benefits associated with the own consumption of biogas and modern biomass.
- Secondary data (reports, surveys) were used, collected from four regions of the country.

KEY FINDINGS

Biogas

- The income of some masons more than doubled thanks to the biogas programme.
- In Tigray and Amhara, masons are paid only with the subsidy from the government. In Northern Ethiopia, the scarcity of wood fuel and associated problems are more severe, and alternatives are essential; the subsidy from the government was key to promoting the construction and use of biodigesters in the area. In Oromia and the Southern Nations, Nationalities, and Peoples' Region, the biogas owners pay an additional amount of 1,114-1,739 Ethiopian birr to masons, depending on the volume of the plant.
- Household income was measured based on cost savings such as savings on wood fuel, charcoal, dung cake, kerosene and chemical fertilizer per year. Only a reduced smaller number of households sell the bioslurry. The biggest savings are associated with the purchase of firewood, followed by fertilizer.
- Biogas users have reduced their expenditures for firewood and charcoal by 45 per cent and 51 per cent, respectively, compared to non-biogas users.
- A small amount of households, especially in Amhara, sell the bioslurry and therefore earn money from it.
- More than 5,175 Ethiopian birr per owner can be saved annually if a farmer installs a biogas plant to use the gas as energy source and the slurry as fertilizer.

Solid biomass

- Most 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,
- Charcoal incurs various costs such as 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.
- Charcoal is among the most important and reliable cash income sources compared to income from semi-subsistence crop and livestock activities that are subject to climatic and other calamities.

- The most frequent channel is from illegal regular household-level producers, to local vendors, to local consumers.
- An average of more than 42,000 sacks of charcoal per day, entering the city of Addis Ababa, was measured in 2012, illustrating the size of the value chain.

KEY MESSAGES

National level

- Better training of masons and better information on households with biodigesters will contribute to increasing the wages and the savings associated with the biodigesters, if households understand well the economic benefits of the digester.
- Monitoring the wages paid in the charcoal sector and the costs/benefits along the supply chain would be extremely useful to reinforce development of the charcoal sector.

MORE IN THE TECHNICAL REPORT

- Channels and locations of charcoal production and distribution.
- Detailed economic benefits and gains attributed to biodigesters.

INDICATOR 12. JOBS IN THE BIOENERGY SECTOR

RESEARCHERS

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DEFINITION

Net job creation as a result of bioenergy production and use, total (12.1) and disaggregated (if possible) as follows: (12.2) skilled/unskilled, (12.3) indefinite/temporary;

(12.4) Total number of jobs in the bioenergy sector;

(12.5) Percentage adhering to nationally recognized labour standards consistent with the principles enumerated in the International Labour Organization's Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors.

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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- 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.

KEY FINDINGS

Biogas

- The biogas pathway resulted in more than 2,000 masons being trained to build biodigesters. This may not always correspond to the creation of new jobs, but it reinforces the availability of work for the masons. The total number of jobs created by the biogas pathway is negligible compared to the total number of jobs in Ethiopia.

SOLID BIOMASS

- The solid biomass sector is the source of many jobs; however, most of them are informal, and there are no specific recorded data on the number of these informal jobs.
- The number of formal jobs is estimated at 12 800 for the wood fuel value chain (jobs in plantation, harvesting, transport, wholesalers, retailing, processing and utilization/ consumption, system and finances) and at 8 450 for the charcoal value chain (production transport, retailing and

consumption as well as management and finances). These numbers do not include informal jobs. The majority of these jobs are unskilled.

- Total jobs, included informal ones, might reach 380 847 permanent jobs and 905 918 seasonal employment opportunities.

KEY MESSAGES

National level

- Better knowledge of the jobs in the bioenergy pathways 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.
- Informal jobs should be assessed, recognized institutionally and converted and organized into formal jobs. Training is extremely important in that sense. For example, charcoal pricing is subject to individual negotiations, and improving the smallholders' bargaining power would contribute to formalization of their job.
- Women and children contribute greatly to the firewood sector, but their activity does not comply with the basic principles of the International Labour Organization. Recognition of this informal activity would help change this situation.
- If the production of charcoal were banned, employment in the sector would certainly shift to wood fuel. Therefore, improving and institutionalizing or legalizing the charcoal sector is probably a more sustainable approach.
- An integrated and well-developed data collection process is required, as well as evaluation and handling mechanisms involving regional and national institutions. The jobs data could be incorporated in one of the national surveys to be conducted by either the Ministry of Water, Irrigation and Electricity or the National Biogas Programme of Ethiopia, with the support of stakeholders in the sector (GIZ, SNV-Netherlands, Ethiopian Environment, Forest and Climate Change Commission, Ethiopian Ministry of Health, Ethiopian Ministry of Women and Children Affairs).

MORE IN THE TECHNICAL REPORT

- Details on job creation associated with biogas, firewood and charcoal; split between skilled and unskilled jobs; share compared to total working population.
- Compliance of jobs with the Declaration on Fundamental Principles and Rights at Work of the International Labour Organization.

INDICATOR 13. CHANGE IN UNPAID TIME SPENT BY WOMEN AND CHILDREN COLLECTING BIOMASS

RESEARCHERS

Alemtsehaye Eyassu, Hundessa Adugna and Gemechu Kaba
Ethiopian Environment and Forest Research Institute (EEFRI), Addis Ababa, Ethiopia

DEFINITION

(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.

MEASUREMENT UNIT(S)

Hours per week per household / percentage

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Secondary data were used, based on literature review. The focus was on the time saved from the replacement of traditional bioenergy (open fires) with improved cookstoves and biogas.

KEY FINDINGS

Biogas

- Over 90 per cent of firewood collection is undertaken by women and children.
- The time savings associated with the use of biogas for cooking reaches up to 3 hours per day, including time reduction for collecting biomass (up to 50 minutes per day), cooking food (up to 100 minutes per day) and cleaning utensils (up to 25 minutes per day).
- The use of biogas increases the average time that women spend collecting dung, fetching water and feeding the biogas digester (up to 30 minutes per day).
- The time saved by women is used for social work (up to 39 per cent), agriculture work (up to 68 per cent), studies (up to 51 per cent), other income-generation activities (up to 33 per cent) and recreation (up to 40 per cent). The share of these activities depends on regions, culture, socioeconomic status, number of family members, exposure and the availability of different community development projects.

Solid biomass

- Studies related to the time savings associated with improved cookstoves are less precise. Fuel savings are estimated at up to 60 per cent, depending on the improved cookstove (the new Gonzie stoves are the most efficient).

KEY MESSAGES

National level

- Other benefits relate to the reduction of gender-based violence and wildlife attack during fuelwood collection.
- The time and workload saved thanks to the modern cooking solution must be well emphasized in clean cooking strategies, so that women and men acknowledge fully this benefit. This could reinforce the sustainability of the adoption of biodigesters and improved cookstoves.
- The change in time spent collecting traditional biomass and cooking with open fires compared to modern cooking solutions is not systematically studied, or studies remain 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 to understand well the dynamics of cooking with different solutions and the associated time, workload and benefits. This will also contribute to understanding the dynamics of fuel and stove stacking.

MORE IN THE TECHNICAL REPORT

- Detailed information on time saved during wood collection, cooking and cleaning utensils, based on several studies.
- Additional social benefits from the use of biogas (gender violence, socioeconomic activities).
- Allocations of the time saved thanks to biodigesters in Oromia, Amhara, Tigray and the Southern Nations, Nationalities, and Peoples' Region.
- References to several surveys conducted in Ethiopia.

INDICATOR 14. BIOENERGY USED TO EXPAND ACCESS TO MODERN ENERGY SERVICES

RESEARCHERS

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DEFINITION

(14.1) Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of (14.1a) energy and (14.1b) numbers of households and businesses;

(14.2) Total number and percentage of households

and businesses using bioenergy, disaggregated into modern bioenergy and traditional biomass.

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 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

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Secondary data were used, retrieved from official reports and literatures.
- Modern energy services are focused on cooking in both pathways. The Global Bioenergy Partnership definition of modern energy services for cooking is based on two criteria: energy efficiency and safety to human health. 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 efficiencies higher than 20-30 per cent, and their flue gases are released distant from their users.

KEY FINDINGS

National level

- Only 10 per cent of households are estimated to have access to modern bioenergy services for cooking, mostly through improved cookstoves.
- According to statistics from the Sustainable Energy for All initiative, only 3.5 per cent of the population has access to clean fuels and technologies for cooking.
- Around 43 per cent of households have access to electricity, and 4 per cent of households cook with electricity. This low value is surprising given the low cost of electricity. Possible reasons for these low values are the low reliability of the grid, upfront costs of electric stoves and cultural factors.

Biogas

- Of the total of 22 166 biodigesters already distributed in Ethiopia, only 77 per cent are functional; hence there are 17 068 households utilizing biogas as modern energy for cooking.
- This represents less than 0.1 per cent of total households.

Solid biomass

- An estimated 11 million improved cookstoves had been distributed in Ethiopia by 2017. The most common types are Mirt and Gonzie (for injera baking) and Tikikil and Lakech (for non-baking services). Their thermal efficiencies are 15 per cent, 15 per cent, 28 per cent and 38 per cent, respectively. According to the recommendations of the Clean Cooking Alliance, only the Tikikil and Lakech stoves are seen as being sufficiently efficient (more than 25 per cent) to be considered improved cookstoves. Tikikil and Lakech stoves are used only by a limited part of the population.

KEY MESSAGES

Biogas

Further expansion of the biodigesters could help rural people in particular to gain access to modern energy services. Agricultural residues, coffee husks, water hyacinth and fruit processing wastes also could be used to feed the biodigesters. As a result, bioenergy development and utilization in the country has a bright future.

Solid biomass

The promotion of more-efficient and cleaner stoves, such as pellet stoves, should be explored. Also interesting are the thermo-electric generation stoves, which provide electricity capacity to charge a phone or a solar lamp.

National level

- With increasing household incomes, there will be a need for cleaner and more convenient energy sources, such as liquefied petroleum gas and electricity, instead of traditional energy sources.
- The specific energy needs for injera baking stoves deserve more analysis. Injera stoves consume a large amount of cooking energy per household, but specific data on these 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.
- 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. It reports 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.

MORE IN THE TECHNICAL REPORT

- Detailed calculation of the number of households with access to modern energy services, the amount of wood and biogas consumed, the equivalent in energy terms and the shares of the total population.
- Comparison with the status quo (open fires).

INDICATOR 15. CHANGE IN MORTALITY AND BURDEN OF DISEASE ATTRIBUTABLE TO INDOOR SMOKE

RESEARCHERS

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DEFINITION

(15.1) Changes in mortality and burden of disease attributable to indoor smoke from solid fuel use;

(15.2) Changes in mortality and burden of disease as a result of the increased deployment of modern bioenergy services, including improved biomass-based cookstoves.

MEASUREMENT UNIT(S)

Percentages

OVERALL METHODOLOGY OF THE IMPLEMENTATION

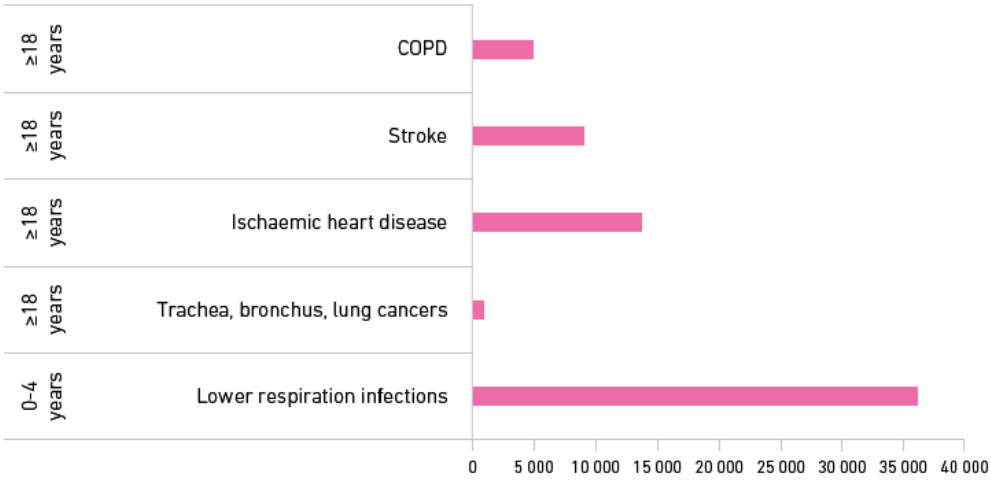
- A review of available studies in Ethiopia was conducted. Particularly useful were data on household air pollution related to biogas and solid fuel from the Ministry of Water, Irrigation and Energy and reports from the Netherlands Development Organization (SNV-Ethiopia). Data from the World Health Organization and regional studies were also used.

KEY FINDINGS

National level

- 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 annually in Ethiopia.
- In most Ethiopian households, cooking is done indoors and often during the night, creating a very smoky environment. This greatly affects women and children. Almost 40 per cent of households cook in the housing units where they live.
- Diseases such as acute lower respiratory infection and chronic obstructive pulmonary diseases can be linked to indoor air pollution. Children under five years of age are particularly affected.

Figure 15.1. Numbers of deaths attributable to indoor air pollution in Ethiopia in 2016



Source: Beyene et al. 2018

Biogas

- The reduction of smoke in kitchens in households that cook with biogas is clearly observed in user surveys. Around 19 per cent of households with biodigesters note that smoke is completely avoided, and 38 per cent report a large reduction in the smoke and health-related impact. Overall, 88 per cent of respondents have observed great improvements in the health conditions of family members since they began using biogas energy.
- Most biogas users continue to use wood, dung or charcoal even after installation of the biodigester. This is known as fuel and stove stacking: households cook with different fuels interchangeably in case of a shortage of biogas due to leakage or improper biodigester feeding practices, or because of preferences for some meals like injera and coffee ceremony. Fuel stacking greatly limits the health benefits of cooking with biogas.

Table 15.1. Use of wood, dung or charcoal for cooking by households with a biodigester in Ethiopia

	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

Solid biomass

- Improved cookstoves also contribute to reducing smoke; however, the World Health Organization considers improved biomass cookstoves to be insufficient in guaranteeing safe levels of indoor air pollution. Only cooking with natural gas / biogas, liquefied petroleum gas, electricity, ethanol, solar and the highest-performing advanced biomass stoves (usually burning pellets) allows for the required low levels of pollution.

KEY MESSAGES

National level

- The development of more-advanced biomass cookstoves is needed to guarantee low levels of indoor air pollution.
- 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.
- More surveys and epidemiological studies on wood fuel use and their health impacts are needed. Monitoring health problems and diseases related to fuel use through surveys in hospitals could also be useful.
- Detailed analysis of the use of fuels interchangeably (fuel and stove stacking) and the impacts on household air pollution also deserves more attention.

MORE IN THE TECHNICAL REPORT

- Detailed analysis of the burden of disease attributable to solid fuel use.
- Statistics on cooking practices.
- Health benefit satisfaction among the users of biodigesters.

INDICATOR 16. INCIDENCE OF OCCUPATIONAL INJURY, ILLNESS AND FATALITIES

RESEARCHERS

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DEFINITION

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

MEASUREMENT UNIT(S)

Percentages

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Review of the secondary data was conducted.

KEY FINDINGS

Biogas

- The major risks identified with biodigesters are accidental fires and fire-related injuries.

Solid biomass

- Injuries while collecting and carrying wood, exposure to wild animal attacks and exposure to violence were noted in national surveys.
- Fire accident is a common risk related to producing and using charcoal. Other major risks with charcoal production are burns, puncher, exposure to smoke, dust and particulate matter, eye disease and miscarriage.

KEY MESSAGES

National level

- Very limited information is available on the incidence of occupational injury, illness and fatalities associated with biogas, firewood and charcoal production in Ethiopia, as well as for related sectors as whole. This is linked to the scarcity of official reports, the lack of mandatory reporting schemes and the absence of disaggregated statistics for bioenergy-specific occupations.

MORE IN THE TECHNICAL REPORT

- Detailed results on the risks and injuries based on surveys on biogas.
- Results for Amhara, Oromia, Tigray and Southern Nations, Nationalities, and Peoples' Region.

INDICATOR 17. PRODUCTIVITY

RESEARCHERS

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DEFINITION

(17.1) Productivity of bioenergy feedstocks by feedstock or by farm/plantation;

(17.2) Processing efficiencies by technology and feedstock;

(17.3) Amount of bioenergy end product by mass, volume or energy content per hectare per year;

(17.4) Production cost per unit of bioenergy.

MEASUREMENT UNIT(S)

(17.1) Tons/hectare per year

(17.2) MJ/ton

(17.3) Tons/hectare per year, m^3/hectare per year or MJ/hectare per year

(17.4) $/MJ

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The indicator focuses on supply rather than on distribution and end use.
- Secondary data were used, retrieved from official reports and literature. Particularly useful were publications from the National Forest Sector Development Program of Ethiopia and its 10-year programme (2017-2025), and from the recent Ethiopian Forest Sector Review technical report.

KEY FINDINGS

Biogas

- Cattle in Ethiopia are mostly range fed, and around 40 per cent of the dung produced is not accessible for collection. Total accessible dry dung is 22.7 million tons annually.
- Biodigesters used in Ethiopia produce, on average, 1,384 MJ/ton of dry dung per day. A total of 17.6 million m^3 per year of biogas production is reported, taking into consideration that only 77 per cent of all biodigesters work (2.8 m^3 produced per day per digester).
- The total cost of biogas production is 0.9 to 2.1 Ethiopian Birr per m^3 ($0.0014 to $0.0032 per MJ) with the governmental subsidy, and 1.2 to 2.8 Ethiopian Birr per m^3 ($0.0018 to $0.0043 per MJ) without the governmental subsidy, depending on the biogas production level.

Solid biomass

- Mean annual increment (MAI) or productivity reaches 2.01 m^3/hectare/year for natural forests, 12.5 m^3/hectare/year for industrial plantation and 15 m^3/hectare/year for woodlot plantations (MEFCC 2018a). The average national MAI of all forests estimated would be 9.7 m^3/hectare/year.
- Charcoal production with traditional kilns is very inefficient, entailing four or five times as much energy input as would be required for burning wood directly (Table 17.1).
- Firewood and charcoal prices are different from production costs. However, due to the lack of more detailed data, prices are used here as a proxy of the production costs. The wood fuel selling price was 240 Ethiopian Birr per m^3 (around $8 per m^3), and the charcoal selling price was 1,840 Ethiopian Birr per m^3 (around $63 per m^3) in 2013.

Table 17.1. Common charcoal production technologies used and conversion efficiency

No.	Production technique	Type of wood	Wood-to-charcoal conversion efficiency in weight (%)	% of users of the techniques
1	**Traditional earth-mound kiln**	Dry/Semi-dry	14.4%	41.5%
2	**Traditional earth-mound kiln**	Wet	< 8.0%	14.0%
3	**Traditional earth pit-kiln**	Dry/Semi-dry	10.3%	34.1%
4	**Traditional earth pit-kiln**	Wet	< 4.1%	10.4%

Source: MEFCC 2016

KEY MESSAGES

Biogas

- 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 households. Therefore, policies should be adopted to help participating individuals and families and the private sector gain access to the necessary capital to build digesters.
- A better understanding of the causes of non-functionality of some biodigesters needs to be developed.
- Agricultural residues and coffee processing wastes are the two other potential and competitive feedstocks for biogas production in Ethiopia.

Solid biomass

- Selecting the best trees (fast growing, high yielding and short rotation) combined with good silvicultural and management practices are recommended solutions.
- Increasing the productivity of charcoal conversion kilns is crucial; strategies for this purpose are presented in other indicators, such as Indicator 24 on training.
- Inter-industry linkages and clusters would lead to utilizing a large amount of waste wood products such as branches, leaves and twigs, off-cuts and sawdust.
- Well-targeted surveys and studies on firewood and charcoal production in Ethiopia are key to identify best practices and best feedstocks for better productivity. Current information is sparse, since a large part of this production is informal.

MORE IN THE TECHNICAL REPORT

- Mean annual increment (MAI) and productivity of different forest types.
- Energy content of different biomass fuels, in comparison with fossil fuels.
- Production cost analysis.
- Potential of bamboo resources.
- Relevance of the 10-year (2017-2025) national forest sector development programme of Ethiopia to address the existing wood fuel demand-and-supply gap by the year 2025.

INDICATOR 18. NET ENERGY BALANCE

RESEARCHERS

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DEFINITION

Energy ratio of the bioenergy value chain with comparison with other energy sources, including energy ratios of: (18.1) feedstock production; (18.2) processing of feedstock into bioenergy; (18.3) bioenergy use; and/or (18.4) life cycle analysis.

MEASUREMENT UNIT(S)

Ratios

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The indicator provides a basis for identifying the most energy-efficient ways to produce bioenergy along the value chain: the more energy consumed during the bioenergy lifecycle, the less energy is available to meet other energy needs.
- Secondary data, literature review and default estimation were used for both pathways.
- Detailed assumptions (distance of transport, efficiencies etc.) are the same as for Indicators 1 and 4, also based on life cycle analysis.
- For solid biomass, the calculation considers two types of feedstocks: *Eucalyptus globules* and invasive *Prosopis juliflor* species. *P. juliflora* is an aggressive and the most invasive species in arid and semi-arid areas, and in pastoral areas. 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 use as wood fuel and charcoal.

KEY FINDINGS

Biogas

- 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 (57 per cent in the best (controlled) conditions of use, and closer to 33 per cent in real (uncontrolled) conditions).
- Production at the biodigester level also represents a potential for efficiency improvement in order to produce more biogas per quantity of dung (0.04 m^3 of biogas per kilogram of dung per day).

Solid biomass

- The main losses occurring in the solid biomass value chain are those related to the conversion of wood into charcoal (efficiency of 17 per cent for traditional kilns) and those 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.

KEY MESSAGES

Biogas

- Better knowledge of the productivity of biodigesters and the efficiency of 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

- The most important improvement potential is related to the carbonization technology: a more efficient carbonization method than traditional approaches (i.e., earth mounds and earth pits) is needed. Firewood and charcoal cookstoves with the highest efficiency should also be fabricated and promoted.

- For Indicator 17, better knowledge of the firewood and charcoal value chain is crucial 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.

MORE IN THE TECHNICAL REPORT

- Energy content of different types of wood and charcoal and of biogas.
- Energy consumed for transport of firewood and charcoal.
- Energy losses associated with leakages (biodigesters), wood-to-charcoal conversion and low efficiency of wood stoves.

INDICATOR 19. GROSS VALUE ADDED

RESEARCHERS

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DEFINITION

(19.1) Gross value added per unit of bioenergy produced and as a percentage of gross domestic product.

MEASUREMENT UNIT(S)

$/MJ, Birr/MJ and percentage

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Secondary data were used for both pathways.

KEY FINDINGS

Biogas

- The gross value added from the biogas value chain was estimated at 176 million Ethiopian birr ($6.2 million) in 2018, considering savings in fuel costs, benefits from increased crop yield and selling bioslurry, and operation and maintenance costs. This is a very small share of total gross domestic product (less than 0.01 per cent in 2018).

Solid biomass

- The gross value added from the value chain of wood fuel (charcoal and firewood) was estimated at 39 billion Ethiopian Birr (almost $1.3 billion) in 2013, accounting for around 4.5 per cent of gross domestic product that year.
- Most charcoal coming to towns and cities is produced, transported and retailed illegally. It is therefore not easy to assess its real contribution the economy. Charcoal producers earn an estimated 75 per cent of the total revenue per bag.

KEY MESSAGES

- The contribution of domestic biodigesters to the national economy will remain small even if a large number of biodigesters are installed. However, the development of biogas for industrial applications or for electricity generation would provide a higher contribution to the economy.
- More systematic studies on the economic contribution of firewood and charcoal are needed.

MORE IN THE TECHNICAL REPORT

- Detailed costs and savings of the biogas pathway.
- Comparison of the results of several studies focused on wood fuel.

INDICATOR 20. CHANGE IN CONSUMPTION OF FOSSIL FUELS AND TRADITIONAL USE OF BIOMASS

RESEARCHERS

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DEFINITION

(20.1) Substitution of fossil fuels with domestic bioenergy measured by energy content (20.1a) and annual savings of convertible currency from reduced purchases of fossil fuels (20.1b);

(20.2) Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content.

MEASUREMENT UNIT(S)

(20.1) MJ per year and/or MW per year;

(20.2) MJ per year

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The required data were obtained from both national and international statistics.

KEY FINDINGS

Biogas

- The annual production of biogas was estimated to be 17.6 million m^3/year in 2018; 3.2 per cent of this is used for lighting and replaces kerosene. This is equivalent to 333,159 litres of kerosene annually, or 14,555 MJ/year. The annual savings are 554 million Ethiopian Birr ($204 074) per year.
- Assuming that 96.8 per cent of biogas is consumed for cooking, this replaces 102,396 tons of firewood (with open fires) annually, considering that 1 m^3 of biogas can replace 6 kilograms of firewood (with open fires).

Solid biomass

- Total firewood and charcoal consumption in Ethiopia in 2018 was 115 million m^3 and 5.4 million m^3 (in wood equivalent to be transformed to charcoal), respectively. An estimated 412 500 tons of firewood was saved by using improved cookstoves, assuming that 1.3 million households use an improved cookstove and that the minimal firewood saving is 300 kilograms per household (this is the estimation for a Tikikil stove).

KEY MESSAGES

- The promotion of clean cooking options is crucial to reduce the use of traditional biomass and fossil fuels for cooking and lighting. This includes innovation in stoves, well-organized markets for firewood and charcoal, and education.
- The promotion of biogas for electricity generation, including cogeneration, deserves attention. This would help reduce the use of fossil fuels for power generation.

MORE IN THE TECHNICAL REPORT

- Detailed assumptions and calculation of the savings in fossil fuel use and the traditional use of biomass.

INDICATOR 21. TRAINING AND RE-QUALIFICATION OF THE WORKFORCE

RESEARCHERS

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DEFINITION

(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.

MEASUREMENT UNIT(S)

Percentage (per year)

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- 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 or certification programme, or that received a degree from a technical school or higher education institution in biogas and/or wood fuel and charcoal in relation to improved cookstoves.

KEY FINDINGS

Biogas

- Close to 2 200 masons were trained in the eight regions where biodigesters were and are being introduced. However, the training of masons is not always sufficient to guarantee the quality of the biodigesters. According to biodigester users, 14 per cent of the masons are not really skillful.
- It is difficult to maintain trained masons in the sector (around one third of the trained mason 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.
- Around 26000 users were trained in biodigesters. The training is usually too limited, particularly in the use of bioslurry. The high illiteracy rate and the large number of mother tongues are barriers to the training.

Solid biomass

- Many different training activities on improved cookstoves have been developed in Ethiopia by many different partners. More than 51 000 people and 1 300 small-scale enterprises are trained to manufacture and distribute stoves in the country.
- Several limitations 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 trainings on production and dissemination, lack of coordination among stakeholders and lack of well-coordinated training for all elements of the supply chain.

KEY MESSAGES

Biogas

- Training is essential to the sustainability of the production, adaptation and adoption of biodigesters and improved cookstoves to ensure their sustainability. Training therefore must involve producers, developers, sellers and users. It is also vital for development of the private sector. However, training must be well thought out and well organized to achieve the expected results, and the bioenergy sector must develop sufficiently in parallel in order to guarantee the retention of workers in the sector.
- Possible activities include: state agencies to provide training in and awareness of biodigesters; active involvement of the private sector and non-governmental organizations in the construction of biodigesters; training of trainers; certification of masons, users and extension workers; a role for the universities; and intensive maintenance training for a few (e.g., three) educated, wise and committed farmers per rural kebele.
- An analysis of the problems encountered with some biodigesters must be done, and solutions must be proposed.

Solid biomass

- Ethiopia's current charcoal production, based largely on inefficient carbonization processes, is a threat to both the local (forestry) and global (climate) environments. 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.

- Possible activities include: training and capacity-building responsibilities identified in national policies; training plans and easy-to-use manuals for charcoal producers; reinforcement of the existing energy centres; processes for wood and cookstove certification; support to community forest associations; establishment of a modern laboratory for cookstove testing and development; charcoal producer surveys and household energy surveys; and awareness activities.

MORE IN THE TECHNICAL REPORT

- Number of trained masons per region.
- Number of biogas construction enterprises.
- Status of producers and importers of appliances and equipment needed by biodigesters.
- Details on training activities organized by stakeholders in the improved cookstove sector.
- Details on proposals to improve the skills of workers and users in the biogas and solid biomass sectors.

INDICATOR 22. ENERGY DIVERSITY

RESEARCHERS

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Kedir Jemal, *Commission of Environment, Forest and Climate Change, Addis Ababa, Ethiopia*

DEFINITION

(22.1) Change in diversity of total primary energy supply due to bioenergy

MEASUREMENT UNIT(S)

Index (in the range 0-1) and MJ bioenergy per year in the total primary energy supply

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The contributions to energy diversity of both biogas and solid biomass have been analysed together. Data on the total primary energy supply of Ethiopia is based on the Energy Balance of the International Energy Agency.
- Energy diversity is measured by the Herfindahl Index. A low index value indicates high energy diversity.
- The Herfindahl Index was calculated in two cases: (1) with modern bioenergy as part of the total primary energy supply, and (2) without modern bioenergy, assuming that the modern bioenergy is replaced by traditional bioenergy.

KEY FINDINGS

- The Herfindahl Index reached 0.8195 with modern bioenergy, compared to 0.8378 considering only traditional bioenergy.
- The high index value indicates the low diversity of the energy supply of Ethiopia.
- The small difference between both cases shows the very limited impact, although positive, of modern bioenergy to the diversity and security of the energy supply in the country.
- The country is still highly dependent on the use of traditional biomass energy sources. In summary, Ethiopia is characterized by a low modern bioenergy share in a poorly diversified supply.

KEY MESSAGES

- The high dependence of the energy supply of Ethiopia on traditional biomass is risky for different reasons, including energy security. Biogas and bioethanol production have started only recently and are expected to grow in the future. This, combined with accelerated penetration of improved cookstoves and improved practices to

produce charcoal, will contribute to a higher diversity of bioenergy sources and therefore higher energy security in Ethiopia.

- Assessing the diversity of 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 (i.e., fuel and stove stacking) are strategies that households use to guarantee energy and cooking security.
- There is no single indicator for energy security: availability, accessibility, adequacy and affordability of energy are interrelated aspects associated with energy security.

MORE IN THE TECHNICAL REPORT

- Detailed definition of the Herfindahl Index.
- Detailed calculation of the Herfindahl Index.

INDICATOR 23. INFRASTRUCTURE AND LOGISTICS FOR DISTRIBUTION OF BIOENERGY

RESEARCHERS

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Kedir Jemal, *Commission of Environment, Forest and Climate Change, Addis Ababa, Ethiopia*

DEFINITION

(23.1) Number and (23.2) capacity of routes for critical distribution systems, along with (23.3) an assessment of the proportion of the bioenergy associated with each.

MEASUREMENT UNIT(S)

(23.1) number

(23.2) MJ, m^3, or tons per year; or MW for heat and power capacity

(23.3) percentages

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- The three subcomponents of the indicator are not fully relevant for the biogas and solid biomass pathways given the nature of the distribution infrastructure: production and consumption of biogas at the same place, and land transport of firewood and charcoal. However, diversification of energy sources and transit routes for energy supplies remains fundamental for energy security.
- The distribution routes for firewood and charcoal are roads. Therefore, the indicators, as defined, are not fully relevant. 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.

KEY FINDINGS

Biogas

- Although there is no challenge with the logistics for biogas distribution, some difficulties may emerge due to the limited local availability of the technology and expertise to build biodigesters, which could limit development of the infrastructure. Two common designs for biodigesters have been installed in the country.

Solid biomass

- The main production areas for firewood occur around and to the east of Lake Tana in the Amhara region. High amounts of wood fuel use are found along the Harerghe highlands and to either side of the Rift Valley in the Southern Nations, Nationalities, and Peoples' Region and the Oromiya region. The potential charcoal production areas in Ethiopia are the Amhara (East Gojam, West Gojam, Agew zone and Gonder), Afar, Oromiya (Borena and Rift valley areas), Southern Nations, Nationalities and Peoples' Region (Omo and Segen areas), Benishangul-Gumuz, Ethiopian Somali and Gambella regions.

- 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 charcoal and firewood production transport continues by truck (Isuzu FSR), with the use of big trucks and local transport to different regions and neighbouring countries.

KEY MESSAGES

- Information on the supply and routes of firewood and charcoal is crucial to better understand the dynamics of the wood and charcoal market and therefore apply appropriate measures.
- The creation of a legal market will help to better know the quantities and routes of these feedstocks.
- Legalization and certification of charcoal producers, distributers and exporters is needed.

MORE IN THE TECHNICAL REPORT

- Detailed description of the logistics for charcoal production.
- Detailed description of the means of firewood and charcoal transport (destination, distance, means of transport, frequency, etc.).

INDICATOR 24. CAPACITY AND FLEXIBILITY OF USE OF BIOENERGY

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DEFINITION

(24.1) Ratio of capacity for using bioenergy compared with actual use for each significant utilization route;

(24.2) Ratio of flexible capacity that can use either bioenergy or other fuel sources to total capacity.

MEASUREMENT UNIT(S)

Ratios

OVERALL METHODOLOGY OF THE IMPLEMENTATION

- Secondary data, literature review and interviews of energy experts were used.
- The first approach used for this indicator 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: households with biodigesters or improved cookstoves usually continue to use traditional ways of cooking. The approach aims to measure the magnitude of fuel stacking, and therefore the potential of increasing the use of modern cooking solutions with bioenergy in households that already use those solutions, but only in a partial manner.

KEY FINDINGS

Biogas

- In households with a biodigester, around 67 per cent of meals are cooked using other cooking methods (firewood, charcoal, etc.). This illustrates the high potential to increase the use of the modern bioenergy solutions following the initial adoption by households.

Solid biomass

- In households already cooking with improved cookstoves, around 71 per cent of meals are cooked using other cooking methods, mostly open fires. Here also, there is a high potential to increase the use of modern bioenergy solutions following the initial adoption by households.

KEY MESSAGES

- Is fuel and stove stacking good or bad? Usually it is considered bad for households that have improved cookstoves to continue cooking with open fires, because indoor pollution remains high in this case. But at the same time, fuel and stove stacking provides flexibility and energy security to households, which is good: for example, if there is a problem with the biodigester, the household still can cook with another option. 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.
- Deeper monitoring of fuel and stove stacking is needed.

MORE IN THE TECHNICAL REPORT

- Number of meals cooked with modern cooking solutions per week.
- Detailed calculation of the indicator for several years

The team of researchers and members of the multi-stakeholder working group (June 2019)

5. CONCLUSION

FROM THE GBEP INDICATORS TO THE SUSTAINABLE DEVELOPMENT GOALS

The implementation of the Global Bioenergy Partnership's sustainability indicators in Ethiopia helped to examine the development of the biogas and improved cookstove sectors and understand how those bioenergy pathways can contribute to reaching the Sustainable Development Goals as well as contribute to national development policies in Ethiopia, such as the Climate Resilience Green Economy strategy.

Access to modern energy, reduction of poverty, better health, increased employment, greater gender equity and climate change are potential benefits of biogas and improved biomass cooking solutions compared with the traditional use of biomass in open fires. The high dependence on biomass, even with the development of improved cookstoves, has downsides and important risks such as deforestation, degradation of soil quality and reduced biodiversity.

FROM A WELL-COORDINATED INSTITUTIONAL FRAMEWORK...

Quantifying, benchmarking, monitoring and improving the sustainability of bioenergy in Ethiopia is highly complicated. Historically, the bioenergy policies, programmes and projects in the country have been administered inconsistently among multiple and different sectors, such as rural development; water, irrigation and energy; and agriculture and natural resources ministries.

Therefore, a strategic recommendation is to establish 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. The multi-stakeholder working group, initiated in the Global Bioenergy Partnership project, deserves to be consolidated and strengthened to support the elaboration of well-coordinated strategies and policies.

...TO A TRIPLE HELIX MODEL OF INNOVATION

The deep collaboration between the concerned Ministries (such as the Environment, Forest and Climate Change Commission; the Ministry of Water, Electricity and Energy; the Ministry of Agriculture; and the Ministry of Innovation and Technology), research institutes and academia (such as the Ethiopian Environment and Forest Research Institute, science and technology universities, the Institute of Technologies; Wondogenet College of Forestry and Natural Resources), and bioenergy producing and processing communities and industries, both in urban and rural areas, is key. A promising axis of research and development is the establishment of an innovative method of tracking and certification that prompts the use of blockchain technology.

RESEARCH, DATA AND STANDARDS

The GBEP indicators illustrate the importance of access to good-quality and detailed primary data, requiring wide geographic coverage and large survey sizes. Strengthening the coordination among regional and national government's institutions is key. An Internet-based platform for bioenergy data collection and handling could facilitate information sharing among regional and national bioenergy experts in the country. The application of the indicators to other bioenergy pathways, such as liquid biofuels, would also be of high interest. Finally, the ongoing efforts of the Ethiopian government to develop national performance standards on cookstoves must be acknowledged. To be impactful, this effort must be supported by an effective regulatory enforcement mechanism.

More reflections and recommendations are proposed in the technical report, available online. https://bit.ly/2pq8kzV

6. 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.

Ethiopia Biomass Energy Strategy (2013). Ministry of Water, Irrigation and Energy. Addis Ababa.

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/.

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 (2018). *National Forest Sector Development Program, Ethiopia. Volume I: Situation Analysis.* Addis Ababa.

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

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

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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