Journal of Renewable Energy and Environment

Journal Homepage: www.jree.ir

Materials and Energy Research Center

MERC

Research Article

Assessing the Environmental Impacts of Biomass Energy Production in Loka Abaya District, Sidama Region, Southern Ethiopia

Ararsa Derese Seboka [a*], Fiseha Bekele Teshome [b], Motuma Tolera Feyissa [a]

[a] *Department of General Forestry, Wondo Genet College of Forestry and Natural Resources, Hawassa University, P. O. Box: 128, Shashemene, Ethiopia.*
[b] *Department of Environmental Science, Wondo Genet College of Forestry and Natural Resources, Hawassa University, P. O. Box: 128, Shashemene, Ethiopia.*

PAPER INFO

Paper History:
Received: 15 March 2022
Revised: 18 June 2022
Accepted: 23 June 2022

Keywords:
Biomass Energy,
Wood Fuel,
Charcoal,
Firewood,
Greenhouse Gases,
Environment Impacts

ABSTRACT

This study was conducted in the Loka Abaya District of Sidama Region, Southern Ethiopia to assess the environmental impacts of biomass energy production with particular emphasis on charcoal and firewood. The data collection was undertaken using the questionnaire survey administered to 186 randomly selected households. This task was followed by key informant interviews and an analysis of the literature. The sampled households produced 208 432.9 kg firewood yr^{-1} for domestic consumption and 261 039.8 kg charcoal yr^{-1} for sale in town. 2.3×10^{-6} km^2 of the forest is cleared to produce a single sack of charcoal. Charcoal and firewood production is totally responsible for the degradation of 39.4 ha of forest per year. The associated emissions of CO_2, CO, N_2O, CH_4, and TNMHC (total non-methane hydrocarbon) during the production and consumption of firewood and charcoal were calculated based on the emission factors indicated by previous studies. The results demonstrated that the trace gases produced during charcoal making were higher than that of charcoal burning. Further, the amounts of greenhouse gases generated during firewood burning were higher than the ones generated during charcoal burning. In order to minimize the challenges of deforestation and greenhouse gas emissions caused by charcoal and firewood consumption, a strategy of promoting the utilization of alternative clean energy sources such as solar and biogas should be implemented in parallel to the effort of adoption of improved biomass energy-saving cook stoves.

https://doi.org/10.30501/jree.2022.334270.1346

1. INTRODUCTION

Global wood removal for wood fuel production is estimated to be 61 per cent [1]; over the last 50 years, global charcoal production increased from 17.3 million tons in 1964 to 53.1 million tons in 2014 [2]. In Sub-Saharan Africa (SSA), the vast majority of households depend on wood energy -comprising firewood and charcoal- for their daily energy requirement; the projection done by International Energy Agency reported that the number of wood-based biomass energy consumers in Sub-Saharan Africa would reach almost one billion by 2030. This indicates that reliance on wood-based biomass energy from firewood and charcoal is far greater in Sub-Saharan Africa (SSA) than in any other region in the world. In 34 countries worldwide, wood-based biomass energy satisfies more than 70 percent of energy needs, and it satisfies more than 90 percent in 13 countries. The majority of these countries are located in SSA [7]. Statistically, Africa accounts for 63 % of the global charcoal production [8]. About 94 % of the African rural population and 73 % of the urban population use wood fuels as their primary energy source with the urban and rural areas heavily dependent on charcoal and firewood, respectively [9].

The Ethiopian total rural household consumption of wood (including the charcoal equivalent of wood) is estimated to be 91.2 million per year with 4.2 million tons per year of charcoal. Total consumption of residues and dung is estimated to be 19.3 million tons per year and 20.7 million tons per year respectively [10]. Biomass energy is highly consumed in rural and urban areas for cooking and heating [11]. Both urban and rural households have upgraded their biomass use from low-quality residues and dung to firewood and charcoal [12]. The availability of these fuels at low cost and the lack of available alternative energy sources are causes for the high dependence of the communities on firewood and charcoal across the country. In urban areas, firewood as the primary fuel varies according to factors such as differences in price and availability of alternatives. Firewood is often burned in open stoves resulting in low energy density and low total energy efficiency during combustion, often between 10 % and 20 %. Furthermore, the difficulty of controlling heat levels in an open stove implies that large masses of fuel must be burned.

Concerning the combustion of firewood and charcoal, the cooking stoves and kitchens are majorly unvented in the study area and this is true for rural households in developing

*Corresponding Author's Email: 20aro201@gmail.com (A.D. Seboka)
URL: https://www.jree.ir/article_160919.html

Please cite this article as: Seboka, A.D., Teshome, F.B. and Feyissa, M.T., "Assessing the environmental impacts of biomass energy production in Loka Abaya district, Sidama region, Southern Ethiopia", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 10, No. 2, (2023), 70-80. (https://doi.org/10.30501/jree.2022.334270.1346).

countries. Consequently, Particulate Matter (PM) and gases such as carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), volatile organic compounds (VOCs), sulphur oxides (SO_x), and a range of trace species including polyaromatic hydrocarbons affect the health of household members directly involved in cooking and heating activities. Furthermore, most of these compounds have a much higher global warming potential than carbon dioxide [13].

The lack of clean alternative energy services in the study areas caused social and economic impacts as well as serious environmental and health problems. The main environmental challenge of the study area was excessive deforestation, which led to the depletion of tree stock, and caused what is known as the household energy crisis in Ethiopia. For the great majority of the population, wood and other biomass fuels are the only sources of energy that have negative environmental, ecological, economic, and health impacts on the lives of the rural poor.

This study was conducted in Loka Abaya district, Sidama Region, Southern Ethiopia. In rural households of Loka Abaya, the inefficient and unsustainable energy production and consumption practices have serious implications for the environment, such as forest resource degradation, land degradation, and tree species diversity loss. In the area, nearly all of the rural households depend on firewood for their cooking requirements, which has led to high deforestation. Furthermore, consumed and produced biomass fuels use smoky and inefficient traditional stoves and kilns. The current study mainly focuses on quantifying the amount of wood removed for fuel in the form of charcoal and firewood as well as assessing their environmental impacts. Specifically, this study is intended to i) estimate the amount of firewood and charcoal produced in the area, ii) analyse the implications of firewood and charcoal production on forest resources, and iii) estimate the number of greenhouse gases emitted during production and consumption.

The study area is the hot spot of firewood and charcoal production mainly for commercial purposes. The environmental consequences of massive wood extraction in the district have not been studied; as a result, there was no meaningful data regarding the amount of wood removed from the area for firewood and charcoal production. Both researchers and development agents have not taken into account the issues of forest resource degradation, biodiversity loss, and emission of pollutants from firewood and charcoal production and consumption. However, the current study mainly (a) focused on generating reliable data that indicate the magnitude of deforestation and forest resource degradation caused by firewood and charcoal production and (b) carried out the estimation of the trace gases emitted during firewood and charcoal combustion.

2. RESEARCH METHODS

2.1. Study area

Loka Abaya District is found in the Sidama region of Southern Ethiopia with a total area of 119,000 ha, at about 325 km south of Addis Ababa. The district is geographically situated between 60 46' N and 380, 04'E. The study area has bimodal rainfall: July to September (heavy rains) and February to April (light rains), the remaining months of the year are fairly dry. The mean annual rainfall and temperature in the area are 1,001-1,400 mm and 17.6-25 °C, respectively [14]. The district is endowed with forest vegetation that is dominated by species such as *Acacia species, Erythrina brucei, Commiphora africana, Albizia gummifera, Balanite eagyptiaca, Ficus species, Cordia africana, Calpurnia aurea, Croton macrostachyus*, and others. Exotic plant species such as *Grevillea robusta, Pinus patula*, *and Eucalyptus and Cupressus lusitanica* occupy the plantation forest of the district.

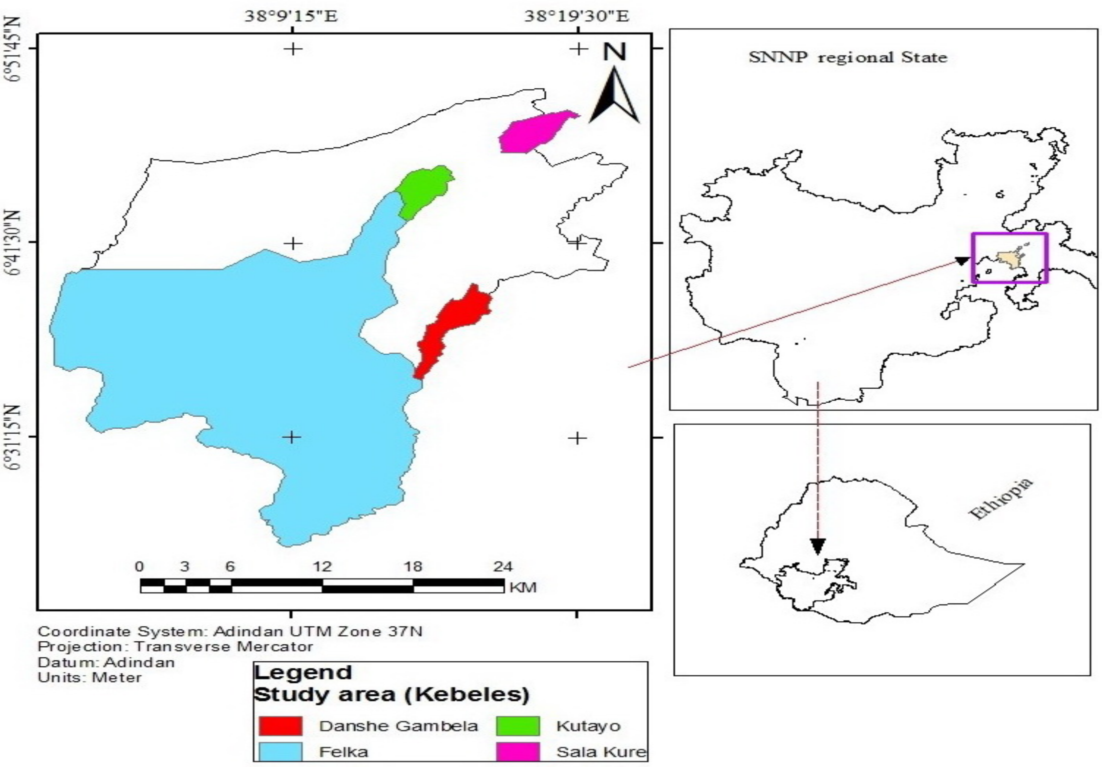

Figure 1. The map of study area

2.2. Data collection and sampling

In sampling, the population of the study multistage sampling was used. The target district was purposively selected based on its potential for charcoal and firewood production. In this study, 5 % of the study populations were randomly sampled for the household surveys. Moreover, the key informants from the energy and agricultural sectors were interviewed to gather general information regarding charcoal and firewood production in the area.

The data of various aspects of charcoal and firewood production were collected through the techniques such as questionnaire surveys, key informant interviews, and literature-based surveys. The questionnaires of different contents were designed and administered to 186 households to gather reliable information from households that use charcoal and firewood at the household level and for sale. Because the amount of wood used to produce these fuels for sale and household level consumption are unquestionably different. Besides, the key informant interview was used to collect qualitative information from government officials, experts, charcoal and firewood sellers, and users.

2.3. Estimation of wood fuel

The estimation of the amount of fuelwood consumed for different household activities such as cooking, heating, and other uses has been undertaken during fieldwork. This was conducted at both the household level and sellers of charcoal and firewood to the nearby towns. The estimation was based on the common weight of a sack of charcoal and a bundle of fuelwood used and sold in the market of the area. The number of households administered in this study was not manageable to carry out the measurements of wood fuels in each household. Thus, a sub-sample of 60 households was selected for wood fuel estimation. Hence, initially, the households were stratified based on family size and wealth categories. Practically, the measurement of charcoal and firewood was carried out by listing the types of meals cooked in the selected households; then, the repetition of each meal cooked per week was recorded and the respondents classified the amount of wood fuel they consume per activity. The data collectors were hired to measure the amount of woo duel using weight balance. In this work, females are entirely engaged in the estimation of wood fuel as the household activities are mainly accomplished by them.

3. RESULTS AND DISCUSSION

3.1. Wood estimation for firewood and charcoal production

The Loka Abaya district is a hot spot for charcoal and firewood production in the Sidama zone. The charcoal and firewood produced in the district are transported to the nearby towns such as Boricha, Dilla, Yirgalem, Hawassa, AletaWondo, and Hantate. This aggravates the environmental degradation in the area. Moreover, the use of inefficient charcoal production kilns and illegal cutting of trees for fuel results in excessive deforestation, land degradation, and emission of green house gases to the environment. This study mainly addressed the environmental impacts of biomass energy production, specifically the problems posed during charcoal and firewood production.

The amount of annual firewood and charcoal produced for household consumption and the market sale was assessed and estimated in kilograms per household. Accordingly, the annual average consumption of firewood and charcoal is estimated to be 1126.6 kg and 702.4 kg, respectively. On the other hand, the amount of firewood and charcoal produced in the district is estimated to be 208432.9 kilograms/year and 261039.8 kilograms/year, respectively (See Table 1). The study conducted in Western Ethiopia estimated that the amount of charcoal production was about 4514400 kg of charcoal used annually in the area [15], which is much higher than the current study. Likewise, the annual firewood consumption presented by [16] is 3635.3 kg of firewood used per household in western Ethiopia, which is higher than the current study. Although there is a difference across the districts, the amount of charcoal and firewood consumed at the district level is an indicator of increased national consumption, which is estimated to be 260,000 tons, all of which was produced by traditional kilns needing at least 2.3 million tons of wood [17]. The household survey revealed that the amount of firewood and charcoal produced in Falka kebele was higher than that in the rest of the target villages, whereas there are no charcoal production activities except firewood in Tula Gorbe kebele.

Table 1. Summary of the monthly production of firewood and charcoal across the study kebeles

Kebeles	Fuel types	Mean	Median	Sum	St. deviation	SE
Kutayo	Charcoal	2308.7	2217.2	48483.1	1856.2	405.05
	firewood	864.7	630	34587.4	1176.9	186.09
Falka	Charcoal	12661.2	3433.7	189918.7	24750.4	6390.5
	firewood	1822.8	630	118485.4	3492.6	433.21
Danshe Gambela	Charcoal	3234	3332	22638	668.87	252.8
	Firewood	644.8	630	25149.4	192.15	30.77
Tula Gorbe	Charcoal	-	-	-	-	-
	Firewood	736.8	750	30210.6	162.9	25.44

3.2. Household's woodfuel consumption and production

In the study area, the household energy sources for cooking and heating include firewood, charcoal, agricultural residues, and animal manure. However, more frequently firewood and agricultural residues are the principal energy sources consumed by the majority of the households. In rare cases, households use animal manure for cooking as it is easily accessible. Charcoal is produced by the households and used as a source of income rather than domestic consumption. As a result, firewood is the dominant household energy source compared to charcoal. The study conducted in the other parts of Ethiopia indicates that almost 100 % of the households subjected to the sampling of their study use firewood as a primary energy source [16].

According to the respondents, firewood is preferred for cooking and heating than other fuels due to its accessibility and affordability. Charcoal is not affordable and needs a lengthy process for production. Nevertheless, the community extensively participates in charcoal production to generate income for their livelihood. This is realized by other studies such that the sale and trading of charcoal and firewood provide an income for the rural communities; particularly, landless and very poor households gather and sell wood for fuel [4].

3.3. Impacts on forest resources

In Ethiopia, wood extraction for domestic firewood or charcoal production constitutes one of the major threats to forests in Ethiopia. The key factors in the increase in fuel production and consumption are mainly urbanization and population growth; as a result, these fuels are highly demanded by urban household markets and other businesses. In the study area, the production and consumption of charcoal and firewood have enormous consequences on the forest resources since the mode of production and consumption of these fuels still remain traditional. This leads to an important waste of wood resulting in the clearance of a large number of trees, as previous studies revealed that 90 % of forest removal was associated with firewood and the production of 3.2 million tons of charcoal in Ethiopia, leading to the overall deforestation rates of 141,000 hectares per year [17]. Consequently, excessive exploitation of forest resources for firewood and charcoal puts pressure on the ecosystem and is ultimately harmful to the environment and biodiversity.

The traditional earth-mound kilns and traditional earth pit-kiln are the two most dominant types of technologies used for charcoal production in the study area, which are similar with kilns used in other African countries such as Mozambique, Malawi, Tanzania Kenya Zambia, and others [15, 18]. Consequently, the wood-to-charcoal conversion efficiency of these technologies is very low. According to Chudimayo and Gumbo [19], average wood-to-charcoal conversion rates of commonly used kilns in tropical regions range from 0.118 to 0.257. Hence, the efficiency of charcoal production in Loka Abaya district of Southern Ethiopia also lies in the same range

Table 2. the forest areas in the study village and their potential of charcoal and firewood production

No.	Kebeles	Name of forest in the locality	Amount of wood fuel produced in Kg per year in each village	
			Charcoal	Firewood
1	Falka	Erbe, wachano, huluto, lukito, shigasha Loka-Merera, sucha, Adama Woda kao, Tulula, Hadho, Dudda Lafa lixa, Mokona, Gado, Kalala	189918.70	118485.40
2	Danshe Gambela	Bukito,Wochano, Erbe, Bikka, Shombicha Shanashno, Dalacha, Sinto, Sinto Molalogn, Argada , Tulo, Chala, Kute Olano, Qararcho, Gado, Gambela, Ogolo Edola, Hogano	22638.00	25149.45
3	Kutayo	Wachano, Lukkito, Chafa, Aga Darba, Chafa, Gada, Gagagsa Dubbisa, Sache, Mereera Lukume, Solosa, Wayicho, Hates, Ogolo She-gasha	48483.10	34587.40
4	Tula Gorbe	Duda, Adama, Gada Mokona, Hadhosa, Etano Gale, Matigola, Lukkito	--	30210.62

3.4. Estimation of forest needed for charcoal and firewood

In this research, the forest area needed to produce firewood and charcoal was estimated, although the amount of wood used to produce a kilogram of charcoal varies depending on the type of woody species and efficiency of conversion methods used for charcoal making and the amount of wood contained in a hectare of forest used for wood fuel production.

The total forest area (ha) that can be deforested each year due to charcoal production in the district was estimated using the model suggested by Chidumayo and Gumbo [19].

$$\text{Deforestation}_{\text{year}}\,(\text{ha}) = \frac{(\text{Charcoal}_{\text{produced}}\ (1/0.19))}{\text{Biomass}_{\text{density}}} \quad (1)$$

The wood-to-charcoal conversion efficiency for the traditional earth mound kilns (0.19) was adopted from Chidumayo et al. [19], and the wood biomass stocking rate for woodland was estimated at 40 ton/ha/yr by FAO [20]. Accordingly, the forest areas cleared due to charcoal production are estimated to be 34.35 ha year^{-1}. Besides, the area of forest needed for firewood is also calculated based on the stock density of the area; thus, the area of forest needed for firewood consumed in the area is 5.2 ha year^{-1}. This study showed that in the Loka Abaya district, charcoal and firewood production was totally responsible for the degradation of 39.4 ha year^{-1} of forest resources each year. The area needed for charcoal production calculated in this research was smaller than the result of the study conducted in Ambo town of Ethiopia, in which 21.2 and 254 hectares of forest were destructed per month and year, respectively [15]. In collective terms, charcoal and firewood based energy demands were identified as a mechanism of forest cover change in Africa [21].

More specifically, it is important to calculate the amount of forest needed to produce one sack of charcoal [22], which is given by:

$$F_s = M_s * E_K * 1/S \quad (2)$$

where M_S is the mass of a single sack of charcoal in tons, E_k is the kiln efficiency (tons of charcoal per tons of wood), and S is the stock density (tons of wood/ha of forest).

According to the sample weight taken in the charcoal market in the area, the average weight of a sack of charcoal is ranging from 45 to 50 kg; hence, the weight of a single sack used in this calculation is 47.5 kg. The calculated area of forest needed to produce a single sack of charcoal in the district is, therefore, estimated to be 2.3×10^{-6} km^2 of forest per year. On the other hand, charcoal and firewood produced from a hectare of forest are estimated to be 5.6 m^3 $ha^{-1}yr^{-1}$ and 29.6 m^3 ha^{-1} yr^{-1}, respectively. This is calculated based on the stock density of the forest of the area. According to Moges et al. [23], the mean annual increment of the woodlands of Ethiopia is 0.79 m^3 ha^{-1} yr^{-1}. Hence, the amount of forest removed for charcoal and firewood production is by far greater than the mean annual increment of the forest. This is an indicator that charcoal firewood production is the major driver of deforestation and forest degradation in the district. A study conducted in the Western part of Ethiopia also realized that the rate of deforestation and forest degradation increased due to the heavy demand for forest products, mainly firewood and charcoal [24].

The result of this study indicates that charcoal production and firewood collection are the main drivers of deforestation and forest degradation in the study area. Because the wood for wood fuel production is most of the time obtained by illegal cutting of wood from the nearby forest areas. According to the key informants, there was high commercialization of charcoal, which is the major cause of deforestation and forest resource degradation in the study area. Studies conducted in this area also realized that commercial charcoal production was linked to forest deforestation and degradation [25]. There is a definite link between wood fuel (charcoal and firewood) use and deforestation [26]. Devendra et al. [27] pinpointed this issue as fuelwood from the forest which is a common source of domestic energy supply in rural and urban areas of developing countries. The experience of African countries also showed that wood for charcoal and firewood production derived from the woodlands, although an insignificant amount also came from plantations and trees outside the forests. The potential for woodland to produce charcoal mainly hinges on the ability of the woody species to regenerate and grow [4].

In the areas where the households depend on biomass energy both for their basic energy requirement and livelihood, there will be continued forest degradation from the legal and illegal use of the forest for firewood and charcoal, despite the protection of the forest. This is the reality in most of the African countries; firewood collection and charcoal production are the main components of this forest degradation in most of the African woodlands [19].

3.5. Long term effect of wood fuel production on forest resources

The forest resources of Ethiopia play significant roles in provisions of energy, construction wood, poles, and timber and non-timber forest products (NTFPs) [28]. There is a significant rate of deforestation in Ethiopia. The main drivers are small-scale farmland expansion and unsustainable fuelwood consumption. The reports indicated that 22.7 % of the African land area was covered by forests, estimated to be 674,419,000 ha. Likewise, the Ethiopian land area that was covered by forest was 11.2 %; this is estimated to be 12,296,000 ha [8]. To be specific, 10,105.2 ha of the land area of the study area (Loka Abaya district) was covered by forest resources [29].

The finding of the current study indicates that the total of 39.4 ha of forest is degraded due to charcoal and firewood production and consumption in the study area. This is evidence that a large area of forest was cleared for the primary energy requirement of the rural and urban communities of the developing countries.

3.6. Greenhouse gas emission estimation

In the study area, charcoal is produced more dominantly using traditional earth mound kilns and traditional earth pit kilns. Consequently, the production is carried out in an oxygen-poor environment, leading to the emission of greenhouse gases such as Carbon dioxide (CO_2), Carbon Monoxide (CO), Nitrous Oxide (N_2O), and Methane (CH_4) and Non-Methane Hydrocarbon (NMHC). In this study, the amount of greenhouse gases emitted from charcoal and firewood production and consumption is calculated based on certain baseline emission factors indicated by the previous studies (Table 3).

The amounts of estimated charcoal and firewood were obtained through the household survey. Accordingly, the estimation for firewood and charcoal is 208432.9 kg yr^{-1} and 261039.8 kg yr^{-1}, respectively. Based on the previously estimated emission factors, the amount of pollutants emitted during charcoal and firewood production and consumption is calculated and presented in Table 4. The presented emission factors of the pollutants are displayed in range; however, the average values of maximum and minimum figures were used in the current study.

Table 3. Emission factors of the greenhouse gases as stated in several studies

Types of fuel	Emission factors					References
	CO_2	CO	N_2O	CH_4	NMHC	
Fuel wood burning	450	43	0.52	1.5	0.125	[5, 21]
Charcoal Burning	170	25	0.29	0.5	-	[6, 2]
Charcoal Production	500	550	0.22	700	355	[2, 7]

Table 4. the estimate of the amount of pollutants emitted during charcoal and firewood production and combustion

Trace gases	Charcoal		Emission during firewood combustion in(T g year $^{-1}$)**
	Emission during production in (T g year $^{-1}$)**	Emission during combustion in (T g year $^{-1}$)**	
Carbon dioxide (CO_2)	1.3×10^{-5}	4.44×10^{-5}	1.3×10^{-4}
Carbon monoxide (CO)	8.96×10^{-6}	6.5×10^{-6}	1.44×10^{-4}
Nitrous oxide (N_2O)	1.084×10^{-7}	7.57×10^{-8}	5.74×10^{-8}
Methane (CH_4)	3.13×10^{-17}	1.3×10^{-7}	1.83×10^{-4}
Total non-methane hydrocarbon (TNMHC)*	2.6×10^{-8}	---	9.27×10^{-5}

* Total non-methane hydrocarbons (TNMHC) are defined as organic compounds excluding methane (CH_4) that contain only C and H; examples include alkanes, alkenes, alkynes, aromatics, and terpenes.
** (T g year $^{-1}$): Tera gram of greenhouse gases per year.

In this study, we have drawn a conclusion that the emission of trace gases produced during charcoal making is higher than that of charcoal burning. Other studies also agree with this result; for example, Kammen and Lew [30] presented that the emission during charcoal production had a greater global warming contribution than emissions from charcoal combustion.

Domestic biomass burning for energy generation constitutes a continuous input of trace compounds into the atmosphere, unlike vegetation fires that represent a seasonal phenomenon [31]. In this study, the amount of greenhouse gases generated during firewood burning exceeds the one generated during charcoal burning (see Figure 2). The study conducted in Zambia by Bertschi et al. [32] is in accordance with the result of the current study; they indicated that fuelwood was used more than charcoal with wood combustion producing 9.8 T g C yr^{-1} as CO_2 and charcoal producing 3.3 T g C yr^{-1}. NO_x was emitted in the lowest quantities from both wood and charcoal.

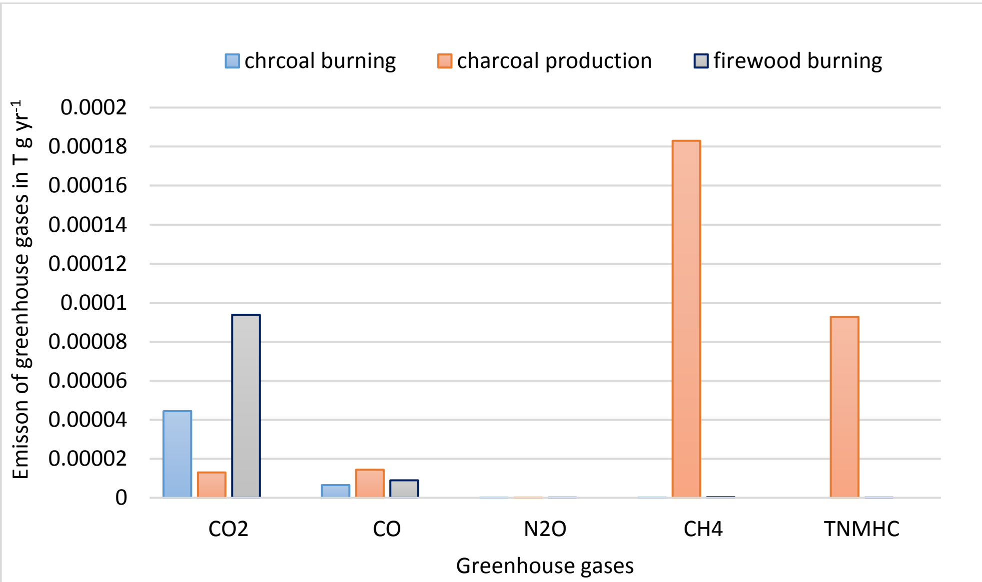

Figure 2. Emission of GHGs during domestic fuel combustion

According to Akagi et al. [33], biomass burning is the second largest source of greenhouse gases and the largest source of primary fine carbonaceous particles in the global troposphere. The emission of trace gases from biomass combustion is one of the important factors for global climate change in developing countries. Firewood and charcoal, animal dung, and agricultural residues account for more than 30 % of the global sources of atmospheric NOx and NMHC, about 40 % of CO emissions, and about 15 % of CH_4 emission [35]. This indicates that the emissions associated with charcoal and firewood production and burning represent a key component of large CO_2 emissions and emission uncertainties on a global scale [34].

3.7. Impact of wood fuel production and consumption on habitat, economy, and society

Forests and woodlands provide not only wood, livestock feed, other non-timber products, and environmental goods and services but also serve as a habitat of biodiversity including endemic birds and wild animals. Forests provide fuelwood that is serving as the major source of energy for rural areas, enhancing the role of the forestry sector in Ethiopia for rural and urban households. The national fuelwood demand was estimated as 20 % higher than the combined demand of all other forest products, which was assessed at 109 million m^3yr^{-1} [36].

The high degree of dependence on wood fuels and agricultural residues for fuel has an impact on the social, economic, and environmental well-being of society. Demand for wood fuels contributes significantly to forest losses and demand for agricultural residues as fuel reduces what is available as livestock feed and what can be left for soil fertility. This could have a direct impact on the economy and the livelihood of the society despite the loss of productivity of land and deficiency of fodder for livestock production. The district is rich in tree and shrub species such as *Comberetum spp., Acacia drepanolobium, A. mellifera, A. seyal, A. tortilies, A. senegal, A. albida, A. nilotica, A. olifera, A. nubica, Aloe vera, Euophorbia tirucalli, Ricinus communes, Caparis tomoentosa, Balanites aegypitica and Balanites routindifolia Ficus sur, Ficus vasta, Petrolatum stelatium, Trechlea sp., Zizihpusspina-christi*, and *Tamarindus indica.*

The Loka Abaya National Park is found in the study area and the district is home to wildlife such as Lesser Kudu (*Tragelaghus imberbis*), Defassa Waterbuck (*Kobus defassa*), Common Bushbuck (*Tragelaghus scriptus*), Lion (*Panthera leo*), Leopard (*Pantera pardus*), and African wild dog (*Lycaon pictus*) [37]. The finding of the current study indicated that the total of 39.5 ha of forest was cleared every year for wood fuel production and consumption in the area. The uncontrolled firewood collection and logging for charcoal production resulted in the migration of wildlife from the area to other places for survival as their habitat was continuously disturbed for firewood and charcoal purposes. Undeniably, these have a direct implication on the economy of the society and the country at large.

3.8. Alternative and sustainable options

In Ethiopia, biomass energy is not sustainably produced and used in general, and it thus is not yet carbon neutral. There is a huge loss of biomass energy during production, transportation, and utilization. Mostly women and girls are involved in the process and are considerably impacted by it. Based on the realities explored in the current study, the authors suggested sustainable options for biomass energy utilization and production for rural and urban households' energy requirements. Accordingly, the key stakeholders in charge of household energy developments raise public awareness of the costs of existing energy losses and associated energy efficiency and conservation benefits and practices. Additionally, it is crucial to enhance the transfer and adoption of efficient and cleaner energy technologies that are appropriate for the socio-economic needs of the society. Lastly, the clean and renewable energy technologies should be based on the local condition and available resources in the study area. The viable alternative clean energy source could be solar energy. Biogas and fuel-saving cookstoves are used to reduce the rate of clearance of forest resources for firewood and charcoal.

3.9. Policy perspectives

The Ethiopian energy policy enacted in 2012 was a set of objectives to promote improved bio-energy conversion technologies including agro-industrial waste for thermal and power applications and biogas from urban, livestock, and poultry waste. These directions were focused on building local capacity in production and generation techniques. The policy also enacted and enforced appropriate charcoal and firewood regulations and recommended a strategy to reduce the rate of deforestation and promote clean energy technology in place. The establishment and enforcement of standard and quality control of different energy technologies was stated in the energy policy of the country [38]. However, the issues depicted in the energy direction were not properly executed. In the current study context, the promotion of clean energy development from locally available feedstock is deemed to be important. Besides, awareness creation and dissemination of fuel-efficient cookstoves through specifying their standard and quality should be implemented and clearly supported by policy and strategy.

4. CONCLUSIONS

As in many African countries, the majority of rural and urban households in Ethiopia depend on charcoal and firewood for their daily energy needs. The expansion of urban areas and population growth have increased the demand for these fuels in the country. In addition to household consumption, the rural households produce charcoal and firewood as means of livelihood; particularly, landless and poor households entirely rely on this business. In the study area, the estimation for firewood and charcoal is 208432.9 kg yr^{-1} and 261039.8 kg yr^{-1}, respectively. Charcoal and firewood production has far-reaching impacts extending across a range of social and environmental and economic aspects of human life. These include health problems resulting from pollutant gases that specifically affect charcoal producers, women and children; environmental impacts are greenhouse gas emissions and depletion of forest resources.

In the Loka Abaya district, the firewood collection and charcoal production were becoming attractive businesses and the farmers are shifting their livelihood from agricultural activities to firewood and charcoal businesses. The finding of the current study indicated that the total of 39.4 ha of forest was degraded due to charcoal and firewood production and consumption in the study area. This implies deforestation is overwhelmingly high in the area as a result of the traditional and inefficient mode of production and consumption of fuels. Consequently, the estimated amount of wood needed for charcoal and firewood production has a major contribution to the deforestation, loss of important native species, and emission of greenhouse gases. Therefore, immediate intervention is needed to retard the rate of vegetation clearance, loss of tree species diversity, and greenhouse gas emissions. Depending on the results of this research, options to produce environmentally viable household energy sources should be deemed important. In order to tackle the problem, priority should be given to adopting improved charcoal production technologies and efficient utilities, developing alternative energy sources (biogas, solar), enhancing wood lots plantation, and promoting incentives that encourage investments in sustainable forest management recommended on the basis of the present study.

5. ACKNOWLEDGEMENT

This research was funded by Hawassa University, Wondo Genet College of Forestry and Natural Resources. Special thanks to the Research and Technology Transfer of the Office of Wondo Genet College of Forestry and Natural Resources for the encouragement and facilitation of our fieldwork. Finally, our acknowledgement goes to the Loka Abaya District Irrigation and Energy office experts for their assistance during data collection.

NOMENCLATURE

CH_4	Methane
CO	Carbon monoxide

CO_2	Carbon dioxide	PM	Particulate Matter
FAO	Food and Agriculture Organization	SOx	Sulphur oxides
ha	Hactare	SSA	Sub Saharan Africa
Kg	Kilogram	$T\ g\ year^{-1}$	Tera gram of greenhouse gases per year
km^2	Kilometer square	TNMHC	Total non-methane hydrocarbon
N_2O	Nitrous oxide	VOCs	Volatile organic compounds
NTFPs	Non-timber forest products		

APPENDIX

Questionnaire survey

Name of Enumerator: ________________________ Date: ___________ Signature: __________
Location: X ____________ Y ____________

I: The socio economic characteristics of the respondents

1. Kebele: ____
2. Sex of respondent (household head) (1=Female, 2= Male): _____
3. Age of respondent: ____
4. Marital status (1=single, 2=married, 3=divorced, 4=widowed, 5=widower): _____
5. Education level (**1**=Illiterate, **2**=Able to read and write, **3**=Lower primary (1-4), **4**=Upper primary (5-8), **5**=High school (9-10), **6**=Preparatory(11-12), **7**=Diploma, **8**=Degree and above): ______
6. Family size of the household: _______________
7. Average landholding size of the household (in ha): ______________
8. Annual Income sources of the households:

No.	Livelihood activity	Annual estimated yield	Estimated annual revenue in ETB
1	Annual mono crop production		
2	Agroforestry		
3	Monoculture perennial crop production		
4	Wood lot		

9. Do you have access to credit services (1=No, 2=Yes): _________ please list credit institutions in your locality and the type of service you are able to access: ____________

____

10. Is there any social safety net programs in your locality? (1=No, 2=Yes): __________ if your answer is yes please indicate the amount of cash income you received in the last two years 2008-2010 E.C if any ____________________
11. Do any of your household member had involved on any non-farm activities? (1=No, 2=Yes) ___________ If your answer is “yes” please complete the table below:

No.	Non-farm activity	Number of household members involved	Annual estimated earned income
1	Beekeeping		
2	Poultry		
3	Charcoal production and marketing		
4	Firewood collection and marketing		
5	Carpentry		
6	Labor market participation		
7	Pity trade		
8	If other please specify?		

II. Production and consumption of woodfuels

12. Which type of fuel is dominantly used in your household? Please give a rank from 1 to 4

No.	Sources	Rank	Remark
1	Firewood		
2	Charcoal		
3	Crop residues		
4	Animal dung		

13. If your household use both firewood and charcoal, please complete the table below:

No.	List of activities	Firewood		Charcoal	
		Bundle (kg) of firewood consumed per activity	Frequency of activities/week	Kg of charcoal consumed per activity	Frequency of activities/week
1	'Injera' baking				
2	Bread baking				
3	Coffee preparation				
4	'Wot' making				
5	Room heating				
6	If other please specify				

14. What are the methods commonly you use to produce charcoal?
(**1**=Earth mound kiln, **2**=Earth pit kiln, **3**= Cassamance kiln, **4**=Metal kiln, **5**=if other please specify) (Multiple answer is possible)
____

Other: ________________________

III. The species and sources of wood for charcoal and firewood production

15. What are the names of forest areas found around your locality?
a) ______________________
b) ______________________
c).______________________
d).______________________

16. Are there areas of forest that degraded due to charcoal and firewood production? a) Yes b) No
17. What class of vegetation used for charcoal production? a) Bushes b) Shrubs c) Trees
18. What class of vegetations used for firewood production? a) Herbs b) Bushes c) Shrubs d) Trees
19. What are the most preferred trees you commonly used to produce charcoal?

a) ____________________ e) ____________________
b) ____________________ f) ____________________
c) ____________________ g) ____________________
d) ____________________ h) ____________________

Criteria of preference:

20. What are the most preferred trees you commonly used to produce firewood?

a) ____________________ e) ____________________
b) ____________________ f) ____________________
c) ____________________ g) ____________________
d) ____________________ h) ____________________

Criteria of preference:

21. Where do you access these trees for charcoal production?
a) Private wood lots b) Communal forest c) State forest d) Clan forest f) All g) Specify if there is another sources
____

22. Where do you access these trees for firewood?
a) Private wood lots b) Communal forest c) State forest d) Clan forest f) All g) Specify if there is another sources
____

REFERENCES

1. FAOSTAT, Food and Agriculture Organization of the United Nations, Statistics Division, Economic and Social Development Department, Rome, Italy, (2016). (https://www.fao.org/faostat/en/#home), (Accessed on 31 December 2016).
2. FAO, "Criteria and indicators for sustainable woodfuels: Case studies from Brazil, Guyana, Nepal, Philippines and Tanzania", Rome, Italy, (2009). (https://www.fao.org/3/i1321e/i1321e01.pdf).
3. Seyoum, Y., Birhane, E., Hagazi, N., Esmael, N., Mengistu, T. and Kassa, H., "Enhancing the role of forestry in building climate resilient green economy in Ethiopia", Center for International Forestry Research Ethiopia Office, Ministry of Environment, Forest and Climate Change, The Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia, (2015). (https://www.cifor.org/publications/pdf_files/Books/BKassa1503.pdf).
4. Msuya, N., Masanya, E. and Temu, A.K., "Environmental burden of charcoal production and use in Dar es Salaam, Tanzania", ***Journal of Environmental Protection***, Vol. 2, No. 10, (2011). (https://doi.org/10.4236/jep.2011.210158).
5. Geissler, S., Hagauer, D., Horst, A., Krause, M. and Sutcliffe, P., "Biomass energy strategy for Ethiopia", AMBERO Consulting Gesellschaft mbH, (2013), 61476. (https://ambero.de/projekte-slug/biomass-energy-strategy-for-ethiopia/).

6. Sitoe, A., Remane, I., Ribeiro, R., Falcão, M.P., Mate, R., Nhamirre, J., Walker, S., Murray, L. and Joana Melo, J., "Identificação e análise dos agentes e causas directas e indirectas de desmatamento e degradação florestal em Moçambique", (2016). (https://www.fnds.gov.mz/index.php/pt/documentos/relatorios/identificacao-e-analise-dos-agentes-e-causas-directas-e-indirectas-de-desmatamento-e-degradacao-florestal-em-mocambique).

7. Akagi, S.K., Yokelson, R.J., Wiedinmyer, C., Alvarado, M.J., Reid, J.S., Karl, T., Crounse, J.D. and Wennberg, P.O., "Emission factors for open and domestic biomass burning for use in atmospheric models", ***Atmospheric Chemistry and Physics***, Vol. 11, No. 9, (2011), 4039-4072. (https://doi.org/10.5194/acp-11-4039-2011).

8. Nike, D. and Meshack, C., "The marginalization of sustainable charcoal production in the policies of a modernizing African nation", ***Frontiers in Environmental Science,*** Vol. 5, (2017), 27. (https://doi.org/10.3389/fenvs.2017.00027).

9. FAO Forestry Paper, "Global Forest Resource Assessment, Progress towards sustainable forest management", 147, (2005). (http://www.env-edu.gr/Documents/Global%20Forest%20Resources%20Assessment%202005.pdf).

10. Malimbwi, R.E. and Zahabu, E.M., "The analysis of sustainable charcoal production systems in Tanzania", Criteria and indicators for sustainable woodfuels: Case studies from Brazil, Guyana, Nepal, Philippines and Tanzania, FAO, Rome, (2008), 229-258.

11. Ludwig, J., Marufu, L.T., Huber, B., Andreae, M.O. and Helas, G., "Domestic combustion of biomass fuels in developing countries: A major source of atmospheric pollutants", ***Journal of Atmospheric Chemistry***, Vol. 44, No. 1, (2003), 23-37. (https://doi.org/10.1023/A:1022159910667).

12. Demeke, A., Sintayehu, T., Ermias, K. and Girma, M., "Diversity and relative abundance of birds in Loka Abaya National Park, Sidama Zone, Southern Ethiopia", ***International Journal of Biodiversity and Conservation***, Vol. 11, No. 8, (2019), 230-240. (https://doi.org/10.5897/IJBC2019.1306).

13. Global Forest Resource Assessment, "Main report", ***Food and Agriculture Organization of the United Nations***, Rome, (2010).

14. Abaynesh, K., Chimdi A. and Akhila S.N., "Effect of firewood energy consumption of households on deforestation in Debis watershed, Ambo District, Oromia Regional State, Ethiopia", ***World Applied Sciences Journal***, Vol. 33, No. 7, (2015), 1154-1163. (https://doi.org/10.4314/star.v4i1.26).

15. Fekadu, G., "Floristic composition and structural analysis of Komto Afromontane Rainforest, East Wollega Zone of Oromia Region, West Ethiopia", Ph. D. Thesis, Addis Ababa University, (2010). (http://thesisbank.jhia.ac.ke/6804/).

16. Esayas, A. and Woldegiorgis, M., "The impacts of charcoal and firewood production and consumption on natural forests surrounding Ambo Town, ISSN, Vol. 6, (2017), 1-20.

17. Kammen, D.M. and Lew,. D.J., "Review of Technologies for the production and Uuse of charcoal", ***Renewable and Appropriate Energy Laboratory Report***, Vol. 1, (2005). (https://www.researchgate.net/profile/Debra-Lew/publication/237577160_Review_of_Technologies_for_the_Production_and_Use_of_Charcoal/links/00463528265a28ccda000000/Review-of-Technologies-for-the-Production-and-Use-of-Charcoal.pdf).

18. Abebe, D., Koch, S.F. and Mekonnen, A., "Coping with fuelwood scarcity: Household responses in rural Ethiopia", Environment for Development Initiative, (2012). (https://www.researchgate.net/profile/Steve-Koch/publication/254446194_Coping_with_Fuel_Wood_Scarcity_Household_Responses_in_Rural_Ethiopia/links/55a6173008aef604aa047498/Coping-with-Fuel-Wood-Scarcity-Household-Responses-in-Rural-Ethiopia.pdf).

19. Devendra, L.P., Kiran Kumar, M. and Pandey, A., "Evaluation of hydrotropic pretreatment on lignocellulosic biomass", ***Bioresource Technology***, Vol. 213, (2016), 350-358. (https://doi.org/10.1016/j.biortech.2016.03.059).

20. Dewees, P.A., "The woodfuel crisis reconsidered: Observations on the dynamics of abundance and scarcity", ***World Development***, Vol. 17, No. 8, (1989), 1159-1172. (https://www.researchgate.net/profile/Peter-Dewees/publication/222238813_The_woodfuel_crisis_reconsidered_Observations_on_the_dynamics_of_abundance_and_scarcity/links/5a2956454585155dd428feb1/The-woodfuel-crisis-reconsidered-Observations-on-the-dynamics-of-abundance-and-scarcity.pdf).

21. Ciais, P., Bombelli, A., Williams, M., Piao, S.L., Chave, J., Ryan, C.M., Henry, M., Brender, P. and Valentini, R., "The carbon balance of Africa: Synthesis of recent research studies", ***Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences***, Vol. 369, No. 1943, (2011), 2038-2057. (https://doi.org/10.1098/rsta.2010.0328).

22. Falcão, M.P., "Charcoal production and use in Mozambique, Malawi, Tanzania, and Zambia: Historical overview, present situation and outlook", ***Proceedings of The Conference on Charcoal and Communities in Africa***, International Bamboo and Rattan Organization (INBAR), (2008). (https://www.inbar.int/resources/inbar_publications/charcoal-and-communities-in-africa/).

23. Feyisa, B.N., Feyssa, D.H. and Jiru, D.B., "Fuel wood utilization impacts on forest resources of Gechi District, South Western Ethiopia", ***Journal of Ecology and the Natural Environment***, Vol. 9, No. 8, (2017), 140-150. (https://doi.org/10.5897/JENE2017.0642).

24. MoWIE, "Ethiopian National Energy Policy (2nd Draft)", Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy (MoWIE), Addis Ababa, (2012). (https://www.devex.com/organizations/ministry-of-water-irrigation-and-energy-mowie-ethiopia-124251).

25. SZBCT (Sidama Zone Bureau of Culture and Tourism), "A report on the boundary demarcation and biological survey of the proposed Loka Abaya National Park in the Sidama Zone, Sidama, Hawassa", Unpublished Report, (2009), 24.

26. MoWIE., "Environmental impact assessment report for Gidabo irrigation project", Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy (MoWIE), Addis Ababa, (2019).

27. Bertschi, I.T., Yokelson, R.J., Ward, D.E., Christian, T.J. and Hao, W.M., "Trace gas emissions from the production and use of domestic biofuels in Zambia measured by open-path Fourier Transform Infrared Spectroscopy", ***Journal of Geophysical Research: Atmospheres***, Vol. 108, No. D13, (2003), 8469. (https://doi.org/10.1029/2002JD002158).

28. Lindesay, J.A., "African savanna fires, global atmospheric chemistry and the southern tropical Atlantic regional experiment", Fire in the Southern African Savanna: Ecological and Environmental Perspectives, Witwatersrand University Press, (1997), 1-15.

29. Jargstorf, B., "Introduction to renewable energy/rural energy: Technology overview and the Ethiopian situation", P***roceedings of Symposium on Renewable Energies in Ethiopia (Mobile Exhibition)***, Addis Abeba, Ethiopia, German Technical Cooperation, (2004). (https://agris.fao.org/agris-search/search.do?recordID=ET2006000014).

30. United Nations (UN), "World population prospects: The 2015 revision, key findings and advance tables", United Nations (UN), Department of Economic and Social Affairs, Population Division, Working Paper No. ESA/P/WP.241, (2015). (https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf).

31. Moges, Y., Eshetu, Z. and Nune, S., "Ethiopian forest resources: Current status and future management options in view of access to carbon finances", Final Report, Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy (MoWIE), Addis Ababa, (2010). (https://www.un-redd.org/sites/default/files/2021-10/ETHIOPIAN%20FOREST%20RESOURCES-%20%20CURRENT%20STATUS%20AND%20FUTURE%20MANAGEMENT%20OPTIONS%20%20IN%20VIEW%20OF%20ACCESS%20TO%20CARBON%20FINANCES%20.pdf).

32. Intergovernmental Panel on Climate Change (IPCC), "Mitigation of climate change-Summary for policymakers", Working Group III: Contributions to the Intergovernmental Panel on Climate Change, Bangkok, Thailand, (2018). (https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg3_full_report-1.pdf).

33. Modi, V., McDade, S., Lallement, D. and Saghir, J., "Energy services for the millennium development goals", (2005). (https://qsel.columbia.edu/assets/uploads/blog/2016/publications/energy-services-for-the-millennium-development-goals.pdf).

34. Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., "High-resolution global maps of 21st century forest cover change", ***Science***, Vol. 342, No. 6160, (2013), 850-853. (https://doi.org/10.1126/science.1244693).

35. Trefon, T., Hendriks, T., Kabuyaya, N. and Ngoy, B., "L'économie politique de la filière du charbon de bois à Kinshasa et à Lubumbashi", (2010). (https://lirias.kuleuven.be/retrieve/173858).

36. Lemenih, M., Bongers, F., Wiersum, K.F. and Art, B., "What the future holds for forestry development in Ethiopia? Foresight through scenarios construction", ***Ethiopia***, (2011), 101.

37. D'Agostino, A.L., Urpelainen, J. and Xu, A., "Socio-economic determinants of charcoal expenditures in Tanzania: Evidence from panel data", ***Energy Economics***, Vol. 49, (2015), 472-481. (https://doi.org/10.1016/j.eneco.2015.03.007).

38. Chidumayo, E.N. and Gumbo, D.J., "The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis", ***Energy for Sustainable Development***, Vol. 17, No. 2, (2013), 86-94. (https://doi.org/10.1016/j.esd.2012.07.004).