Contribution of Bioenergy to the Modern Energy Services in Ethiopia

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Abstract

Biomass based traditional energy has been the main energy supply in Ethiopia. Efforts are being made to shift to modern bioenergy utilization but the level of contribution of modern bioenergy to the total energy supply of the country's supply is not computed. In this synthesis we described the contribution of bioenergy to modern energy utilization in the country. Data used here was retrieved from the country's official reports and published literatures. Access to modern cooking services in the country was particularly focused on and both biogas feedstock productivities and biogas processing efficiencies were calculated. Herfindahl Index (HI) was calculated to observe the change in the diversity of the total primary energy supply due to bioenergy in the country. Results indicated that only a few households, 10%, had access to modern bioenergy services. Less than 0.10% of households have a biogas digester. The HI values showed the low diversity of the energy supply and the very limited contribution of modern bioenergy. This synthesis indicated that the contribution of modern bioenergy to the energy supply of the country is very low. Very low difference was observed between Herfindahl Indexes with and without considering modern bioenergy in the total primary energy supply (TPES) of the country is also found to be insignificant. Results found indicated lower diversity of the energy supply of Ethiopia and very limited contribution of modern bioenergy to the diversity and security of the energy supply.

Introduction

It has been stated that access to modern energy is an essential and a fundamental means for a better life of mankind [1]. Ethiopia is found to be rich with different estimated renewable energy resources such as hydropower (45 GW), wind (10 GW), geothermal (5 GW) and solar irradiation (7.5 kWh/m²/day) [2]. But the country is still highly dependent on traditional biomass energy sources and where 91% of energy consumed in the country is primarily obtained from biomass [3]. Particularly, about 63.3% of households in the country use a three-stone stove as their primary stove [4].

This huge dependency on traditional use of biomass for energy generation has been condemned for its contribution to environmental degradation [5-7]. Hence, Ethiopia is putting different efforts to reduce dependency on the traditional way of biomass utilization as energy source. Large-scale hydroelectric projects with the aim of increasing the supply of renewable energy sources is being developed [8]. Biogas production and utilization has been promoted to the rural households through the national biogas program (NBPE) [9]. Similarly, promotion on the utilization of energy efficient technologies like improved cookstoves is being carried out [10,11].

Universal energy access has been defined as access to clean, reliable and affordable energy services [12]. Such access could primarily be achieved through providing affordable access to modern energy services [13]. Likewise, modern energy services have been defined based on energy efficiency and safety to human health [14]. An increase in the access to modern energy services gained through modern bioenergy indicates positive impact on sustainable development of a country. Similarly, an increase in the number of households and businesses using modern bioenergy also represents a positive contribution to the sustainability of the country's energy mix. The higher the number of bioenergy sources means the more diversified and the secured energy mix. The deeper examination of the diversity of bioenergy sources of a country will help to know how robust these energy supplies are. Hence, the objectives of this research work are (a) to determine how bioenergy helped to get access to the modern energy services of Ethiopia (b) to determine the biogas productivity status in the bioenergy supply of the country and (c) to measure the energy diversity in the total primary energy supply (TPES) of the country.

Materials And Methods

Bioenergy used to expand access to modern energy services

The amount of increased access to modern energy services gained through modern bioenergy was measured in terms of energy and household numbers. The number of households using bioenergy (both modern bioenergy and traditional biomass) was measured [14, 15]. Secondary data retrieved from official reports and literatures was used for this purpose. The synthesis particularly focused on measuring the access to modern cooking services in Ethiopia.

According to the Global bioenergy partnership (GBEP) [14] definition of modern energy services for cooking is based on two criteria: energy efficiency and safety to human health. This definition was considered during categorizing energy access as modern energy. Where modern energy services rely on the combustion of fuels, the fuels must be burned in efficient and safe combustion chambers, improved cookstoves, or fuel cells. Improved cookstoves considered were both closed stoves with chimneys and also open stoves or fires with chimneys or hoods. But open stoves or fires with no chimney or hood were excluded. Improved cookstoves considered were those which have energy efficiency higher than 20-30 per cent and their flue gases are released distant from their users.

Biogas productivity

Both feedstock productivities and processing efficiencies by technology/feedstock were calculated [16–17]. The amount of bioenergy end product by mass/volume or energy content was also calculated. Furthermore, the production cost per unit of bioenergy was measured. Measuring the productivity here focuses on the productivity of the land used to produce bioenergy, as well as the overall economic efficiency of the production.

Energy diversity

Herfindahl Index (HI) was calculated to observe change in diversity of total primary energy supply (TPES) due to bioenergy. Data on TPES of Ethiopia was based on the energy balance of the international energy agency [18]. The Herfindahl Index (HI) was calculated using the following formula.

$$HI = \sum_{n=1}^n Si^2$$

Where: Si = Share of energy sources in TPES and n = Number of energy sources in TPES. The HI can range from 0 to 1. HI = 0 when n = ∞, HI = 1 when n = 1. Therefore, a smaller index, closer to 0, indicates higher energy diversity.

Results And Discussion

Bioenergy used to expand access to modern energy services

Modern energy services gained through modern bioenergy

Total final energy consumption in Ethiopia was 42.15 Mtoe in 2016 [18]. 90% of this final energy was consumed by households. Fuels from solid biomass (fuelwood, charcoal, animal dung and crop residues) were the main energy sources for cooking. But most of them were used in a traditional way as three-stone open fires and cannot be considered as modern energy end-use. The question was therefore to assess the amount of fuelwood used for cooking that can be considered as providing modern bioenergy services.

(a) Improved biomass cookstoves

According MEFC [19], total consumption of biomass reached 100 million tons in 2013 and 140 million tons when residues and dung were added. Gaia Association [20] reported the number of households in Ethiopia to be 18,627,682 (77% rural and 23% urban). The author also indicated that these households used more than 122 million tons of biomass, which was the same order of magnitude as MEFC [19]. This results in an average of more than 5,000 kg biomass fuel per household per year (more than 7,000 kg if residues and dung are included).

On the other hand, a total of 9 million improved cookstoves were distributed to the households during the GTP I program of the country (2011-2015) [21]. The improved cookstoves distribution to the households of Ethiopia reached 11 million by 2017. *Mirt* and *Gonze* (for *Injera* baking) and *Tikikil* and *Lakech* (for non-baking services) were the most common improved cookstoves in the country. Their thermal efficiencies were 15%, 15%, 28% and 38%, respectively, [21] and they had an average thermal efficiency of 24%. According to the recommendations of the clean cooking alliance, only the *Tikikil* and *Lakech* stoves were considered sufficiently efficient (more than 25%) to be considered improved cookstoves. But these improved cookstoves (*Tikikil* and *Lakech*) are still used by a limited part of the population.

In summary, only around an estimated 10% of households were found to use efficient stoves (for baking), and penetration of other modern and clean cookstoves was well below 10% [21]. According to sustainability for all statistics, only 3.5% of the population has access to clean fuels and technologies for cooking [22].

For this study, we assume an optimistic value of 10% of households using improved biomass cookstoves considered as modern cooking solutions. An average energy efficiency of 28% was considered for the improved biomass cookstoves, which was a little bit optimistic, and 8% for the other stoves. Considering a total biomass consumption of 122 Mtons of fuelwood, a total of 3.75 Mtons/yr of fuelwood (1299 ktoe/yr) was consumed by the households with improved cookstoves, and 118 Mtons/yr by the households without improved cookstoves (Table 1). Taking the efficiency of the stoves into consideration, this corresponds to modern energy services of 364 ktoe/yr.

Table 1: Computation of Indicator 14 for solid biomass

Characters	Households with modern biomass cooking solutions	Households without modern biomass cooking solutions
Mton biomass		122
Total households		18.6
Share	10%	90%
Million households	1.86	16.74
Efficiency of the stove	28%	8%
Ton biomass/household/yr	2.02	7.06
Ktoe biomass/household/yr ¹	0.000699	0.00245
Mton biomass/yr	3.75	118.25
Ktoe biomass/yr ¹	1 299.81	40 943.91
Ktoe energy service/yr ¹	363.95	3 275.51
Ktoe energy services/household/yr ²	0.000242	0.000242

TPJ = 23.88 ktoe; 1 GJ = 0.00002388 Ktoe; ¹Assumption: 14.5 MJ/kg wood; ²Heat available for cooking (produced by the stove)

(b) Biogas

It was reported that the highest estimated potential of biogas production in Ethiopia under high scenario is about 3.5 million biodigesters (Fig. 1) [23]. But only few of this potential were distributed yet. From the total of 22,166 biogas digesters already distributed in the country [23] (Fig. 2), only 77% were found functional. Hence 17,068 households were utilizing biogas as modern energy. Each biogas digester produces an estimated 2.83 m³ of biogas per day [21], and the efficiency of the biogas stove was 57%. This results in a final energy consumption of 9.3 ktoe/yr. This was found be equivalent to energy services of 5.3 ktoe/yr (Table 2).

Table 2: Computation for biogas used to expand access to modern energy services

Characters	Households with biogas cooking solutions
Million households with functional biogas digester	0.017
Efficiency of the stove	57%
m ³ biogas per household	2.8
m ³ biogas/household/yr	1 033.0
Ktoe biogas/household/yr ⁽¹⁾	0.0005427
Million m ³ biogas/yr	17.6
Ktoe biogas/yr ⁽¹⁾	9.3
Ktoe energy service/yr ⁽²⁾	5.28
Ktoe energy services/household/yr ⁽²⁾	0.0003093

¹Assumption: 22 MJ/m³ biogas; ²Heat available for cooking (produced by the stove)

(c) Electricity

The main energy resource used in electricity generation in the country is hydropower. The country's electricity power system consumes 832 ktoe of hydropower [24]. According to these authors, 38.7% of electricity is consumed in the residential sector (35.8% for lighting and 1.32% for cooking services). Hence, it was computed that 11 ktoe of hydropower electricity is used for household cooking services in the country.

(d) Fossil-fuel services

According to SNV [21], of the 36.4 Mtoe generated in Ethiopia in 2014, 8% is from petroleum. Yurnaidi and Kim [24] showed further that 1.43% of energy from fossil fuel goes for residential cooking service. Hence, only about 41.6 ktoe used for cooking services is from fossil fuel.

Synthesis

The access to modern cooking energy services was, therefore, estimated to be a total of 426.3 ktoe, i.e., 364 ktoe from improved biomass cookstoves, 9.3 ktoe from biogas digesters, 11 ktoe from electricity services and 42 ktoe from fossil fuel services. Cooking services with traditional cooking solutions was computed to be 4,044 ktoe. Hence, the total access to modern cooking energy services is very small compared to the cooking services from traditional sources.

Modern energy services gained through number of households

The modern energy services gained through number of households was synthesized as follows.

(a) Improved biomass cookstoves

As has already been indicated above, around 11 million cookstoves had been distributed by 2017. However, as discussed above, many of them cannot be considered as improved cookstoves given their low efficiency. Based on SNV [21], we assumed that 10% of households use improved biomass cookstoves considered as modern cooking solutions according to the usual definitions.

(b) Biogas digesters

From the total of 22,166 biogas digesters already distributed in the country (UNEP, 2019), only 77% are functional, and hence 17,068 households utilize biogas as modern energy. This represents less than 0.1% of total households.

(c) Electricity services

It has been reported that 42.9% of the Ethiopian population had access to electricity, broken down into 85.4% of the urban population and 26.5% of the rural population. Assuming that the same rate applies to households (this assumption neglects the different sizes of households in urban and rural areas), the number of households with electricity was 8 million, or 3.3 urban households and 3.9 rural households. Moreover, it was estimated that 4.1% of households cook with electricity [4]. This low value is surprising given the low cost of electricity. The low reliability of the grid, upfront costs of electric stoves and cultural factors are possible reasons for these low values.

Synthesis

In total, 1.9 million households have access to modern cooking services and 8 million households have access to electricity services. Ethiopian households with access to modern energy could be estimated by summing households with access to bioenergy and electricity, but this needs to consider that some households have access to both. Due to the lack of data, we considered that half of the households with access to modern cooking services also have access to electricity services, i.e., 0.95 million households. This results in about 8.9 million households with access to modern energy services.

It is interesting to note here that the total number of households with modern cooking services was found to be less than the urban households with electricity access, which proves that many urban households still do not have access to modern cooking services. The percentage of households with access to modern energy through bioenergy was calculated using the following formula and result obtained was 21% (1.9/8.9).

$$\% = \frac{\text{No. of HH with access to modern energy from modern bioenergy}}{\text{No. of HH with access to modern bioenergy}} 100$$

Households using modern bioenergy and traditional biomass

Based on the data provided above, the total number of households using bioenergy was summed up to be 18.6 million households of which 1.9 (10%) from modern bioenergy services and million and 16.7 (90%) million from traditional bioenergy services.

Biogas productivity

Biogas digesters being promoted and distributed to households in Ethiopia are mainly dependent on manure feedstocks. According to Tucho and Nonhebe [10], there are more than 54 million head of cattle in Ethiopia. Bond and Templeton [25] reported an average amount of 700 kg of dry dung per cattle per year. This results in production of 37.8 million tons of dry dung per year in the country.

Unfortunately, cattle in Ethiopia are mostly range fed, and around 40% of the dung produced is not accessible for collection. Hence, the total accessible annual dry dung is only 22.68 million tons per year. Moreover, since biogas digesters are in principle distributed to households with at least four head of cattle [26], the corresponding annual dung production of the household is estimated to be at least 2,800 kg of dry dung per year per household.

Agricultural residues and coffee processing wastes are the two other potential and competitive feedstocks for biogas production in Ethiopia. The total potential supply of agricultural residues in the country is about 22.4 million tons per year [27]. On the other hand, Ethiopia is the fifth largest coffee producer in the world. Bickford [28] indicated increased annual coffee production in Ethiopia, which was expected to reach 441,000 metric tons in 2019/2020. Wondwosen et al. [29] estimated that for every 2 kg of coffee beans produced; approximately 1 kg of husk is generated. Hence, about 220,500 tons of coffee husks could be produced in 2019/20 and could theoretically be used for biogas production.

To date, cattle dung is the main biogas feedstock used for biogas production in the country and hence only the biogas amount from this feedstock was estimated here.

(a) Processing efficiency

The most frequently distributed biogas digesters in the national biogas program of Ethiopia (NBPE) is the 6 m³ biogas digester known as *Sindu*, a Nepalese model [30]. This represents 89% of all biogas digesters distributed in the country so far [31]. The program, through its NBPE-I, NBPE-II and NBPE+ implementations, has already distributed a total of 22,166 biogas digesters [9]. According to Senait [31], around 2.83 m³ of biogas is produced by this biogas digester type per day, using 45 kg of dry dung. With the assumption that 1 m³ of biogas is equivalent to a calorific value of 22 MJ, hence the production of biogas per biogas digester reaches 1,384 MJ/ton of dry dung per day (2.83/0.0045 x 22).

(b) Amount of biogas volume per year

A total of 22,166 biogas digesters were already distributed to different regions of the country [9]. This corresponds to a daily producing capacity of 62,730 m³ biogas per day (22,582,721 m³ of biogas per year), assuming the most frequent size of the biogas digester (6 m³). However, the household survey outcome of MoWIE [32] revealed that only 77% of the distributed biogas digesters were functioning due to lack of maintenance, change in farming practices, lack of water and lack of interest. The highest functionality rate of biogas digesters was observed in southern nations, nationalities and peoples region (SNNPR) and the least in Tigray (Fig. 2). As a consequence, biogas production was estimated at only 48,302 m³ per day (17,630,205 m³ per year) in the country.

(c) Biogas production cost

The calculation was proposed for a 6 m³ biogas digester. The cost assumptions are described in Table 3. Two levels of biogas production are considered (high and low) [33]. The resulting cost of biogas production is 0.9 to 2.1 birr/m³ (0.0014 to 0.0032 \$/MJ) taking into account the government subsidy, and 1.2 to 2.8 birr/m³ (0.0018 to 0.0043 \$/MJ) without the government subsidy (Table 3). This considers no labour cost and no discount rate.

Table 3: Cost of biogas production

Inputs		
Subsidy	6 000 birr	
Investment before subsidy	17 340 birr	867 birr/yr
Investment after subsidy	11 340 birr	567 birr/yr
Lifetime	20	
O&M, share of investment	2%	347 birr/yr
Biogas production (high)	2.83 m ³ /day	1 033 m ³ /yr
Biogas production (low)	1.2 m ³ /day	438 m ³ /yr
Results		
Annual cost w/o subsidy	1 214 birr	
Annual cost with subsidy	914 birr	
High biogas production		
Cost biogas w/o subsidy	1.2 birr/m ³	0.0018 \$/MJ
Cost biogas with subsidy	0.9 birr/m ³	0.0014 \$/MJ
Low biogas production		
Cost biogas w/o subsidy	2.8 birr/m ³	0.0043 \$/MJ
Cost biogas with subsidy	2.1 birr/m ³	0.0032 \$/MJ

Energy diversity

The total primary energy supply of Ethiopia reached 51.54 Mtoe in 2016 [18]. Biofuels and traditional uses of biomass (open fires), modern uses of solid biomass (improved cookstoves), biogas and bioethanol were considered for this energy diversity study. Specific consumption levels were synthesized as follows.

About 449 ktoe of biomass was used with improved cookstoves (Table 4). The annual production of bioethanol from sugar factories was 128,165,000 litres in 2014, equivalent to 65 ktoe (1 m³ bioethanol = 0.51 toe) [34]. Since more recent data is not available, the same amount was considered in 2016. About 17,388,695 m³ biogas was computed to be produced annually from the working installed digesters, which was equivalent to 9.3 ktoe (Table 2).

To assess the contribution of modern bioenergy to the diversity and security of the energy supply in Ethiopia, the country's Herfindahl Index was calculated in two cases: (a) with modern bioenergy as part of the TPES and (b) without modern bioenergy, assuming that the modern bioenergy is replaced by traditional bioenergy (Table 4).

Table 4: Herfindahl Index of the country with and without modern bioenergy

Source of energy	With modern bioenergy			Without modern bioenergy		
	Primary energy (ktoe)	S	S ²	Primary energy (ktoe)	S	S ²
Biofuels and waste		47 048		47 048		
Biomass (traditional)	46 452	0.90280.8151		47 048	0.91290.8334	
Biomass (improved cookstoves)	449	0.00870.0001		-	-	-
Bioethanol	65	0.00130.0000		-	-	-
Biogas	7	0.00010.0000		-	-	-
Hydro, geothermal, solar	950	0.01840.0003		950	0.01840.0003	
Coal	272	0.00530.0000		272	0.00530.0000	
Sum	51 806	HI 0.8195		51 806	HI 0.8378	

The Herfindahl Index reached 0.8195 with modern bioenergy, compared to 0.8378 considering only traditional bioenergy. This computation has indicated that the contribution of the total modern energy to the energy diversity remains very small. The contribution of biogas to the diversity was also found very insignificant. The country is still highly dependent on the utilization of traditional biomass energy sources. In summary, there is a low modern bioenergy share in a poorly diversified energy supply of the country.

Conclusions

Bioenergy used to expand access to modern energy services

Only 10% of households are estimated to have access to modern bioenergy services, mostly through improved cookstoves. Around 43% of households have access to electricity, and 4% of households cook with electricity. Less than 0.1% of households have a biogas digester.

Further expansion of biogas digesters could help rural people in particular to gain access to modern energy services. Some people have already gained exposure to the benefits that could be obtained by having biogas digesters. The cattle population in Ethiopia is also very high to provide dung as a feedstock for anaerobic digestion. For biogas to enhance access to modern energy services, support is required from government policies, such as the national energy policy. This would facilitate the development of the biogas market and the application of advanced technologies so that biogas can be used in an efficient

and safe way. Of course there are also competitive alternative feedstocks for biogas production in the country, such as agricultural residues, coffee husks, water hyacinth and fruit processing wastes. As a result, bioenergy development and utilization in the country has a bright future.

The share of households using improved cookstoves is found to be progressing. The promotion of more efficient and cleaner stoves, such as pellet and briquette stoves, should be explored. Other interesting stoves are the thermo-electric generation stoves, providing electricity capacity to charge a phone or a solar, where excess heat is converted to electricity.

Biogas productivity

The theoretical and accessible annual dry dung production in Ethiopia is 22.68 million tons. Agricultural residues and coffee processing wastes are the two other potential and competitive feedstocks for biogas production in Ethiopia. However, cattle dung is now the main biogas feedstock used for biogas production in the country. The most frequently distributed biogas digesters in the NBPE is the 6 m³ biogas digester known as *Sindu*. It produces around 2.83 m³ biogas per day, or 1,384 MJ/ton of dry dung per day. A total of 17,388,695 m³ per year of biogas production is reported, taking into consideration that only 77% of all biogas digesters work. The total cost of biogas production is 0.9 to 2.1 birr/m³ considering the government subsidy, and 1.2 to 2.8 birr/m³ without the government subsidy, depending on the biogas production level.

The analysis shows that biogas may be an effective option to replace fossil fuels and other less efficient and sustainable biofuels. Even if the cost of biogas production itself is low, the cost of building biogas digesters is high compared to the revenues of the households. Therefore, policies should be adopted to help the participating individuals, families and private sectors gain access to the necessary capital to build digesters. Moreover, a better understanding of the causes of non-functionality of some biogas digesters needs to be developed.

It is also important to remember that biogas production can provide many socioeconomic benefits, which should also be monitored. Some of these benefits are: new job opportunities, use of renewable energy sources from materials that would otherwise be disposed of, reducing the quantity of imported kerosene and other energy sources, and the generation of digestate reduces the use of inorganic fertilizers. These benefits deserve to be monetized and internalized in the computation of the production costs.

Energy diversity

Availability, accessibility, adequacy, affordability of energy are interrelated aspects associated with energy security. The synthesis was to look at how potential interruptions to energy supply based on the diversity of the energy supply: the higher the number of bioenergy sources, the more diversified and secure the mix of supply.

The Herfindahl Index with modern bioenergy reaches 0.8195; it reaches 0.8378 without considering the modern bioenergy in the TPES. These results indicate 1) the low diversity of the energy supply of Ethiopia (high value of Herfindahl Index); and 2) the very limited contribution, although positive, of modern bioenergy to the diversity and security of the energy supply due to the low levels of energy supply by biogas, solid biomass used in improved cookstoves, and bioethanol.

The high dependence of the energy supply on traditional biomass is risky for different reasons, including energy security. The modern bioenergy potential has not been fully exploited so far in Ethiopia. Biogas and bioethanol production have started only recently and are expected to grow in the future. This combined with an accelerated penetration of improved cookstoves and improved practices to produce charcoal, will contribute to a higher diversity and therefore a higher energy security in Ethiopia. In other words, higher penetration of modern bioenergy will clearly contribute to the energy diversity and therefore the energy security of the country.

Declarations

We, the authors of this manuscript, wish to confirm that there is no conflict of interest associated with this publication. We confirm that the manuscript has been read and approved by all named authors. The order of authors listed in the manuscript has also been approved by all of us. We confirm that we have followed the regulations of our institutions concerning intellectual property. We understand that the Corresponding Author is the sole contact for the Editorial process and he is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Conflict of interest

The authors declare that there is no conflict of interest.

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Figure 1

Biogas potential (digesters) of some regions of Ethiopia

Figure 2

Biogas digesters distributed by the national biogas program of Ethiopia (NBPE) during its different phases of implementation

Figure 3

Functionality rates of biogas digesters by region (%). Data source (31).