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Research Article

Contribution of Bioenergy to the Modern Energy Services in the Total Primary Energy Supply of 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 were retrieved from the country's official reports and published literature. 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 was very low. A 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.

Keywords: Energy diversity; TPES; Energy mix

ABBREVIATIONS

HI: Herfindahl Index; TPES: Total Primary Energy Supply; GHG: Green House Gases; NBPE: National Biogas Program of Ethiopia; GTP: Growth and Transformation Program; SE: Sustainable Energy; SNNPR: Southern Nations, Nationalities and People's Region; EEFRI: Ethiopian Environment and Forest Research Institute.

INTRODUCTION

The global energy demand is sharply increasing due to the rapid growth of population and the advancing industrialization [1]. Despite of this growth, the largest portion of the energy market is dominated by fossil fuels [2], which contribute to the Green House Gases (GHG) emissions [3-5]. Use biomass energy in a traditional way, particularly in developing countries, has been condemned for its contribution to environmental degradation [6,7].

Ethiopia's access to modern and clean energy supplies is one of the lowest in the World. Biomass, in a traditional way of energy generation, is the major energy source accounting for 87% of the total energy supply in the country [8]. The total energy consumption by all sectors of the economy in the country in 2017 was 38,964 ktoe (9% from petroleum products, 2% from coal, 2% from electricity and 88% from biomass) [9]. Nevertheless, there are large variations on the current energy systems in rural and urban areas. Almost all rural areas households depend on traditional fuels for cooking compared to the urban households. The household sector is a major energy consuming sector accounting for 88.2% followed [9].

The Ethiopian government is trying to shift to the energy source to a clean and renewable energy supply for its economy and flourishing infrastructures [8]. Large-scale hydroelectric projects with the aim of increasing the supply of renewable energy sources are being developed. Biogas production, from available

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biomass, and utilization have been promoted to the rural households through the National Biogas Program of Ethiopia (NBPE) [10]. Similarly, promotion on the utilization of energy efficient technologies, such as improved cookstoves, has been carried out [11-14].

Universal energy access has been defined as access to clean, reliable and affordable energy services [15]. Such access could primarily be achieved through providing affordable access to modern energy services [16,17]. Modern energy services have also been defined based on energy efficiency and safety to human health [18-20]. An increase in the access to modern energy services gained through modern bioenergy indicates a positive impact on sustainable development of a given country [21]. Similarly, an increase in the number of Households (HHs) and businesses using modern bioenergy also represents a positive contribution to the sustainability of the country's energy mix [22,23]. The higher the number of bioenergy sources, the more diversified and secure energy mix is [24]. The deeper examination of the diversity of bioenergy sources of a country will help to know the robustness the energy supplies. Hence, the objectives of this research work is to determine how bioenergy helped to get access to the modern energy services in the country and to measure the energy diversity in the TPES mix of the country.

MATERIALS AND METHODS

Secondary data sources such as published and unpublished official reports, policy issue papers, published journal articles and relevant websites on energy production and utilization in the country were used for this synthesis research. The documents were collected from the energy based participating government and non-government partners like NBPE, SNV-Netherlands/ Ethiopia and Ministry of Water, Irrigation and Electricity.

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 in this case [18,22]. Improved technologies considered were based on the definition of modern energy services for cooking (energy efficiency and safety to human health) (18) and based on the efficient and safe combustions [25]. Improved cookstoves considered were both closed stoves with chimneys and also open stoves or fires with chimneys or hoods [26]. 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 distantly from their users.

Both biogas feedstock productivities and processing efficiencies by feedstock were calculated [27,28]. The amount of biogas end product by mass/volume or energy content was also calculated [29]. Furthermore, the production cost per unit of bioenergy was measured.

Herfindahl Index (HI) was calculated to observe change in diversity of TPES in the country due to bioenergy. Data on TPES of Ethiopia was based on the energy balance of the international energy agency [30]. The Herfindahl Index (HI) was calculated using the following formula. For this calculation, different sources of energy generations in the country were obtained.

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

Modern energy productions in the country

The According to IEA [30], total final energy consumption in Ethiopia was 42.15 Mtoe and about 90% of this final energy was consumed by households [31]. Fuels from solid biomass (fuelwood, charcoal, animal dung and crop residues) were the main energy sources for cooking in the country. But most of these biomass types 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.

Improved biomass cookstoves: Gaia Association reported the number of households in Ethiopia to be 18,627,682, of which 77% were in the rural area and 23% were belonging to the urban areas. It was also indicated that these households used more than 122 million tons of biomass [32,33]. This results in an average of 5,000 kg biomass fuel per household per year and more than 7,000 kg if residues and dung are included.

On the other hand, a total of 11 million improved cookstoves were distributed to the households during the first Growth and Transformation Pro0067ram (GTP I) of the country. MIRT cookstove and GONZE cookstove (for Injera baking) and TIKIKIL cookstove and LAKECH cookstove (for non-baking services) were the most commonly promoted improved and distributed cookstoves in the country. Their thermal efficiencies were 15%, 15%, 28% and 38%, respectively [34]. Only TIKIKIL and LAKECH cookstoves were considered sufficiently efficient (more than 25% thermal efficiency) to be considered as improved cookstoves [35]. In summary, only around an estimated 10% of households were found to use efficient stoves (for baking) [34]. On the other hand, SE for ALL reported that only 3.5% of the country's population has access to clean fuels and technologies for cooking [36].

For this study, we assume an optimistic value of 10% of HHs using improved biomass cookstoves considered as modern cooking solutions. An average energy efficiency of 33% was considered for the improved biomass cookstoves, which was a little bit optimistic, and 15% 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 HHs with improved cookstoves and 118 Mtons/yr by the HHs without improved cookstoves (Table 1). Taking the efficiency of the cookstoves into consideration, this corresponds to modern energy services of 364 ktoe/yr.

Table 1: Modern bioenergy from 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]	1299.81	40943.91
Ktoe energy service/yr[1]	363.95	3275.51
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).

Biogas: The estimated potential of biogas production in Ethiopia under a high scenario is about 3.5 million biogas digesters (Figure 1) [35]. But only a few of these potentials were promoted and distributed to date by the NBPE. From the total of 22,166 biogas digesters already promoted and distributed in the country [35] (Figure 2), only 77% of them were found functional [37]. Hence, 17,068 households were utilizing biogas as modern energy. Considering the estimated capacity of 2.83 m^3 of biogas per day per digester [34] and the 57% efficiency of the biogas stove being used in the country, the final energy consumption of 9.3 ktoe/yr was computed. This was found to be equivalent to the energy services of 5.3 ktoe/yr (Table 2).

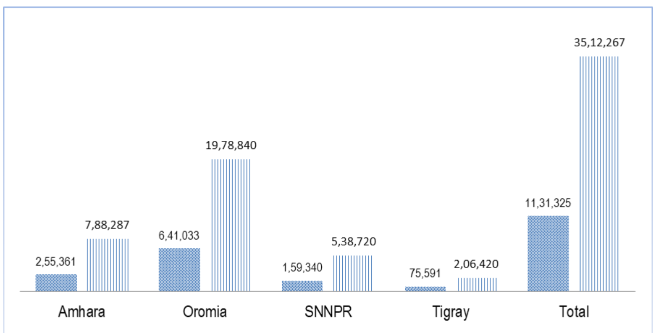

Figure 1: Biogas potential (digesters) of some regions of Ethiopia. **Note:** (▩) Low scenario; (|||) High scenario.

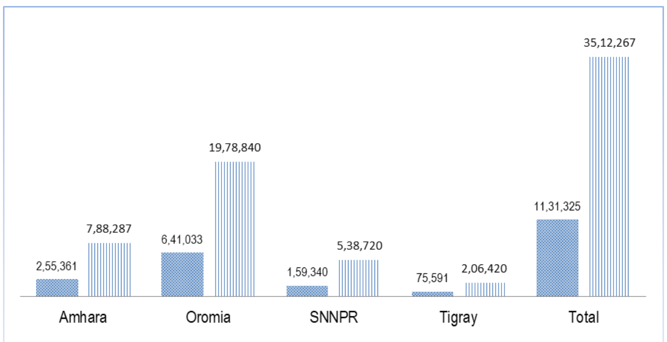

Figure 2: Functionality rates of biogas digesters by region (%). Data source [47]. **Note:** (▩) Low scenario; (|||) High scenario.

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

Electricity: Hydropower is the main energy resource of electricity generation in the country [38]. The country's electricity power system generates 832 ktoe of hydropower annually [39]. About 38.7% of electricity generated 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 HHs cooking services in the Ethiopia.

Fossil-fuel services: According to SNV [34], of the annual 36.4 Mtoe generations in country, 8% is contributed from petroleum. Yurnaidi and Kim [39] showed 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.

Modern energy services gained through number of HHs

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

Improved biomass cookstoves: As has already been indicated above, around 11 million cookstoves had been distributed by 2017. However, many of them cannot be considered improved cookstoves given their low efficiency. Based on SNV [34], we assumed that 10% of HHs use improved biomass cookstoves considered as modern cooking solutions.

Biogas digesters: From the total of 22,166 biogas digesters already promoted and distributed in the country [35], only 77% are functional, and hence 17,068 HHs utilize biogas as modern energy. This represents less than 0.1% of total HHs. 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 HHs with electricity was 8 million or 3.3 urban HHs and 3.9 rural HHs. Moreover, it was estimated that 4.1% of HHs cook with electricity [40]. 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.

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

Biogas productivity

Potential biogas productions per available feedstock: Biogas digesters being promoted and distributed to households in Ethiopia are mainly dependent on manure feed stocks. According to Tucho and Nonhebe [41], there are more than 54 million heads of cattle in Ethiopia. On the other hand, Bond and Templeton [42] reported an average amount of 700 kg of dry dung per cattle per year. This value 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 about 40% of the dung produced is not accessible for collection [41]. 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 heads of cattle [43]; 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 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 [44]. On the other hand, Bickford [45] indicated 441,000 metric tons of coffee production in 2019/2020 in Ethiopia. Sime et al. [46] estimated that for every 2 kg of coffee beans produced; approximately 1 kg of the husk is generated. Hence, about 220,500 tons of coffee husks could be annually produced and 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.

Processing efficiency: The most frequently distributed biogas digesters in the NBPE are the 6 m^3biogas digesters known as SINDU (Amharic name) a Nepalese model [47]. This represents 89% of all biogas digesters promoted in the country so far [48]. The program, through its NBPE-I, NBPE-II and NBPE+ promotion implementations, has already distributed a total of 22,166 biogas digesters [10]. According to Seyoum [48], around 2.83 $m^3$of biogas is produced by this biogas digester type per day, using 45 kg of dry dung. With the assumption that 1 m^3 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.

Amount of biogas volume per year: As already stated, a total of 22,166 biogas digesters were already distributed to different regions of the country [10]. This corresponds to a daily producing capacity of 62,730 m^3biogas per day (22,582,721 $m^3$of biogas per year), assuming the most frequent size of the biogas digester (6 m^3). However, the household survey outcome of MoWIE [37] 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 People's Region (SNNPR) and the least in Tigray (Figure 3). As a consequence, biogas production was estimated at only 48,302 m^3per day (17,630,205 m^3per year) in the country.

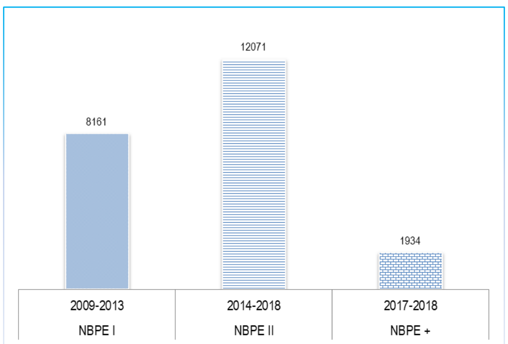

Figure 3: Biogas digesters distributed by the National Biogas Program Of Ethiopia (NBPE).

Biogas production cost: This calculation was proposed for a 6 m^3 biogas digester. The cost assumptions are described below (Table 3). Two levels of biogas production are considered (high and low) [49]. The resulting cost of biogas production is 0.9 to 2.1 birr/m^3($/MJ 0.0014 to $/MJ 0.0032) taking into account the government subsidy, and 1.2 to 2.8 birr/m^3 ($/MJ 0.0018 to $/MJ 0.0043 without the government subsidy (Table 3). This considers no labour cost and no discount rate.

Table 3: Cost of biogas production in the country.

	Inputs	
Subsidy	6000 birr	
Investment before subsidy	17340 birr	867 birr/yr
Investment after subsidy	11340 birr	567 birr/yr
Lifetime	20	
O&M, share of investment	2%	347 birr/yr
Biogas production (high)	2.83 m^3/day	1033 m^3/yr
Biogas production (low)	1.2 m^3/day	438 m^3/yr
Results		
Annual cost w/o subsidy	1214 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 TPES of Ethiopia reached 51.54 Mtoe in 2016 [30]. Traditional uses of biomass (open fires), modern uses of solid biomass (improved cookstoves), biogas and bioethanol were considered for this energy diversity study. The 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 liters, equivalent to 65 ktoe (with the assumption of 1 m^3 bioethanol=0.51 toe) [50]. About 17,388,695 m^3 biogas was computed to be produced annually from the working installed biogas 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). 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.

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		47048		47048		
Biomass (traditional)	46452	0.9028	0.8151	47048	0.9129	0.8334
Biomass (improved Cook stoves)	449	0.0087	0.0001	-	-	-
Bioethanol	65	0.0013	0	-	-	-
Biogas	7	0.0001	0	-	-	-
Hydro, geothermal, solar	950	0.0184	0.0003	950	0.0184	0.0003
Coal	272	0.0053	0	272	0.0053	0
Sum	51 806	HI	0.8195	51 806	HI	0.8378

DISCUSSION

Due to its potential benefits, provision of clean and universal energy has been a growing concern in the world. Efforts have been made by the Ethiopian government to provide clean energy for its HHs through promotion of clean cooking services. Results indicated that of the 18.6 million HHs using bioenergy in Ethiopia, only 10% of them are obtaining modern bioenergy services while 90% million HHS still depend on traditional bioenergy services. Less than 0.1% of total HHs use biogas as a modern bioenergy access. Similarly Dioha and Emodi [51] reported a 94% of Nigerian HHs still depend on traditional biomass energy sources for their cooking energy requirement. The situation is even more pronounced in the rural areas depending solely on fuelwood for cooking.

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. When compared to the Kenyan annual primary energy use/energy supply of 25100 ktoe of which biofuels and waste contributed 16208 ktoe, Ethiopia's total modern cooking energy supply is very minimal [52].

Despite of the available potential feedstock, the biogas production in Ethiopia is very low which of course necessitates further promotion and dissemination of biogas technologies. With the computed 23 million tons dry dung potential per year 18 million m^3 biogas per year can be produced in the country. Its production cost is also found to be 0.9 to 2.1 birr/m^3taking the government subsidy in to account, and 1.2 to 2.8 birr/m^3 without considering the government subsidy.

Herfindahl indices with modern bioenergy and with traditional bioenergy alone were only slightly varied. This very small difference between the two indices indicates that the contribution of the total modern energy to the energy diversity of the country remains very small. Similarly, the contribution of biogas to the energy diversity was also found to be very insignificant. This low index indicates that the country is still highly dependent on the utilization of traditional biomass energy sources and there is a low modern bioenergy share in a poorly diversified energy supply of the country. Kenyan energy mix is far better than the Ethiopian case [53].

CONCLUSION

Bioenergy used to expand access to modern energy services

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. Further expansion of biogas digesters could help rural people in particular to gain access to modern energy services. 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 feed stocks 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 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, better understanding of the causes of the non-functionality of some biogas digesters needs to be developed.

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 could be 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 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.

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CONFLICT OF INTEREST

None to report

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