Hindawi
Journal of Energy
Volume 2023, Article ID 8849321, 11 pages
https://doi.org/10.1155/2023/8849321

*Research Article*

# Green Energy: An Ideal Energy Solution for Sustainable Development of Afar Region, Ethiopia

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Received 29 December 2022; Revised 8 February 2023; Accepted 24 February 2023; Published 24 March 2023

Academic Editor: Qiliang Wang



Green energy is the primary concern for the sustainable development of Ethiopia's Afar region. The study's goals are to present scientific evidence of the Afar region's energy potential to researchers and industry sectors. We used solar shortwave, radiation transfer model, miniscale meteorological model for the Weather Research Forecast (WRF), and spatial and temporal simulation as research techniques. The data show that the Afar region has an energy potential of 239.9 $W/m^2$ average solar radiation flux, 2.102 $MW{\cdot}h/m^2$ average annual solar density, 131.18 $W/m^2$ average wind power density at $h = 10$ m, and 204.5 $W/m^2$ average wind power density at $h = 50$ m. We discovered that solar energy and wind energy are potential energy sources in the Afar region for energy consumption such as solar cooking, solar lighting, and small DC applications.

## 1. Introduction

Green energy is a promising alternative energy that provides a wide range of services such as lighting, heating, cooling, mechanical energy, electricity, and mobility. Green energy is at the heart of sustainable development due to the diversity of climate change and environmental perspectives. Green energy sources have enormous potential because, in the opinion of researchers they have an infinite resource for the world's energy requirements. Green energy (GE), such as biomass, hydropower, geothermal heat, solar energy, wave energy, ocean thermal energy, and wind energy, is derived from natural sources and replenished through regular processes, as illustrated in Figure 1. Green energy has many advantages, including being completely free, emitting little carbon dioxide, being environmentally friendly, and not being reliant on any single country [1, 2]. Most sub-Saharan African countries, including Ethiopia, have faced numerous obstacles to the development of their energy sectors, including energy access, a lack of grid infrastructure, insufficient financial and technical support, political stress, and an excess of energy export [3, 4]. Ethiopia is a landlocked country in the Horn of Africa that is located between 33° and 48° east longitude and 3° to 15° north latitude. Ethiopia has a total land area of approximately 1.13 million square kilometres. Ethiopia has a population of more than 110 million people, but 83% of them live in rural areas. Despite having enormous energy potential, Ethiopia suffers from severe energy shortages [5, 6]. Free energy sources and the reduction of indoor air pollution are linked to the sustainable development program. Ethiopia's power sector has limited access to energy and is highly dependent on nonrenewable resources. Recently, Ethiopia experienced dramatic economic growth; these rapid developments will need a rapid expansion of alternative energy sources. But only 45% of Ethiopia's population has access to electricity, only 24% of primary schools, and only 30% of health centres [7, 8]. There is a large variation in energy access between rural and urban areas; only 5% of rural communities have access to electricity, compared to 87% of urban residents [9–13].

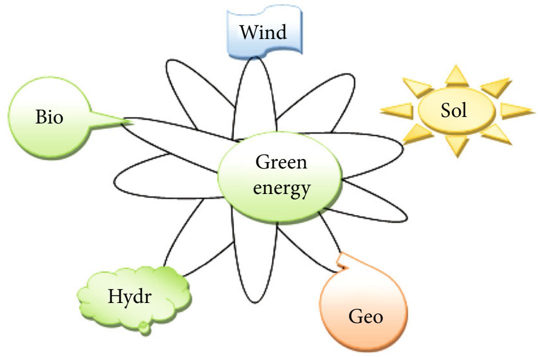


Figure 1: Different green energy sources. Bio: biomass energy; Hydro: hydropower energy; Geo: geothermal energy; Sol: solar energy; Wind: wind energy.

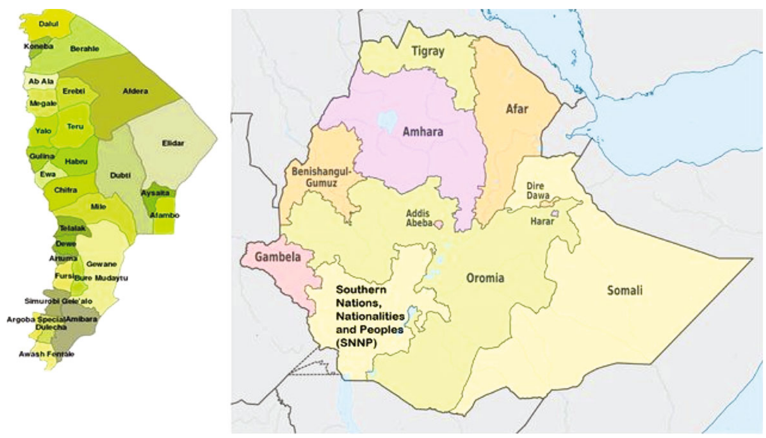


Figure 2: Map of Afar region, Ethiopia.

According to a recent report, 83% of rural areas relied on wood, animal waste, and biomass energy for cooking and heating. Kerosene and dry cell batteries are also used for lighting and low-voltage appliances [14, 15]. The use of biomass is wasteful and has negative socioeconomic, environmental, and economic repercussions [16, 17]. The Afar region is one of the eleven recently created regional states, as shown in Figure 2. It is home to the Afar people and is situated at 11.45°N and 41°E, with Samara as its capital [18]. The average temperature range in its climate is a luminous 27°C to 50°C [19]. Therefore, ventilation and air conditioning are important issues for both workers and living conditions in the Afar region.

The energy industry in the Afar region currently relies on hydropower. Due to significant capital investment, a low load factor, poor voltage guidelines, and frequent power supply disruptions, the Afar region is suffering from a severe energy shortage. By enhancing education, lowering indoor air pollution, and ensuring environmental sustainability, access to renewable energy accelerates both income-generating activities and the regional development program. Transmission losses will also affect the reliability of the rural grid's power supply. Ethiopia's economy has recently experienced dramatic growth, and sustainable development calls for energy that is both accessible and affordable. Additionally, photovoltaic energy has the potential to replace the current operating system with a different primary energy source [12]. This paper proposes to provide scientific knowledge about potential green energy for sustainable development and to conduct widespread research on the green energy potential of the Afar region.

## 2. Green Energy in Ethiopia

*2.1. Current Energy Scenario in Ethiopia.* Ethiopia's primary energy source is around 91% biomass, 7% petroleum, 2% hydropower, and less than 1% other forms of energy for total energy use. Because Ethiopia is one of the fastest-developing countries in the region, its energy needs have recently increased significantly. Ethiopia is gifted with an abundance of renewable energy sources, including geothermal energy of 5 GW, wind energy of 10 GW, hydropower of 45 GW, and an average exploitable solar flux density of 5.5 kWh/m$^2$/day as shown in Figure 3.

However, the total amount of renewable energy exploited is significantly low. For example, only around 5000 MW of the 45,000 MW hydropower potential has been utilized, 324 MW of the 1350 GW wind power potential has been utilized, and 7.3 MW of the 7000 MW geothermal potential has been utilized. On the other hand, Ethiopia has a huge potential of natural gas (113 Bm$^3$) and coal (300 MT), but are completely unexploited (Figure 3) [13].

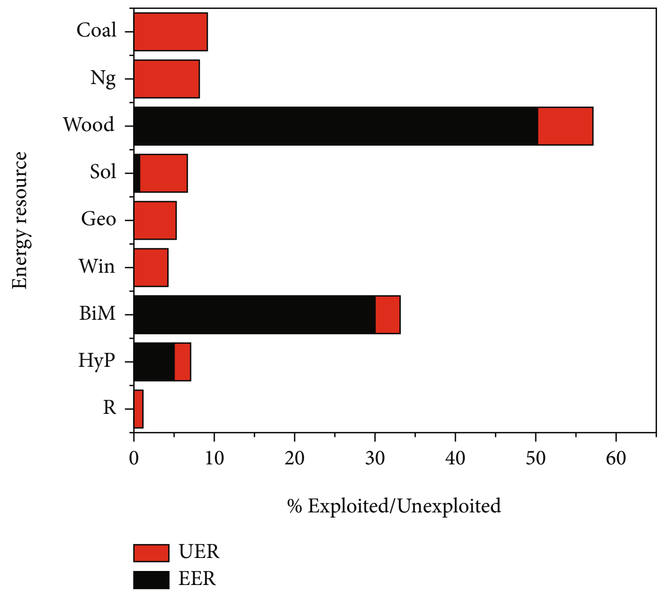


Figure 3: Ethiopia exploited and unexploited energy potentials [19] (Ng: natural gas; Sol: solar; Geo: geo thermal; Win: wind; BiM: biomass; HyP: hydropower; R: reserved).

Table 1: Energy demand forecast from 2015 to 2037 in a different sector. AS(GWh), IS (GWh), SS (GWh), and TS (GWh).

| Years | AS (GWh) | IS (GWh) | SS (GWh) | TS (GWh) |
|---|---|---|---|---|
| 2015 | 623 | 3244 | 1758 | 513 |
| 2020 | 3438 | 7326 | 2209 | 1711 |
| 2025 | 7178 | 20,761 | 3403 | 2976 |
| 2030 | 10,913 | 29,169 | 5568 | 4739 |
| 2035 | 14,580 | 36,431 | 8784 | 7354 |
| 2037 | 15,996 | 51,155 | 15,392 | 8427 |

AS: agriculture sector; IS: industry sector; SS: service sector; TS: transport sector.

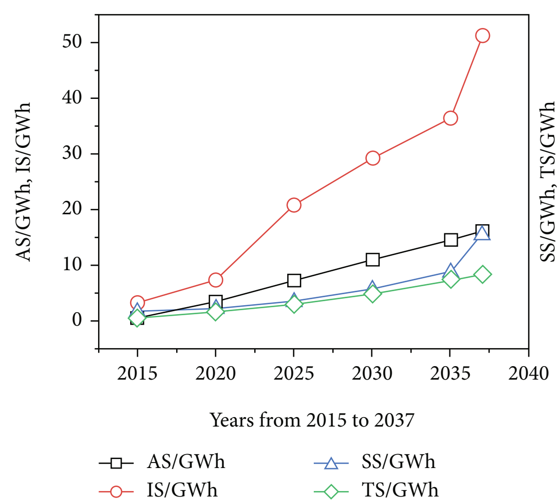


Figure 4: Energy demand forecast of the following sectors (demand forecast in GWh from 2015 to 2037 [19]): AS: agricultural sector; IS: industry sector; SS: service sector; TS: transport sector.

Despite having a lot of energy that can be extracted, Ethiopia still experiences energy shortages on the order of 30% annually [14].

The Growth and Transformation Plan (GTP), which is aimed at making Ethiopia a middle-income country by 2025, was the inspiration for Ethiopia's biggest dream and led to the development of the country's energy sectors. Based on previously presented energy scenarios, four sectors, that is, the agriculture, industry, service, and transportation sectors, are highly energy-demanding areas for the successful realization of the GTP plan, as shown in Table 1 [15, 16].

Figure 4 shows energy demand forecasts for various sectors from 2015 to 2037. Energy demand in the agriculture sector increased by 25.67% from 623 GWh to 15,996 GWh; in the industry sector, it increased by 16.07% from 3244 GWh to 52,155 GWh; in the service sector, it increased by 8.7%; and in the transport sector, it increased by 16.4% in energy per time and power as shown in Table 1 [17, 18]. It implies that the energy demand for the industrial sector is significantly higher than that for the other sectors such as agriculture, services, and transportation. This shows that Ethiopia is developing more quickly [20]. To meet the nation's needs for power generation capacity over the upcoming years, development should be carefully coordinated with energy needs.

*2.2. Green Energy in Africa.* This section provides an overview of the East Africa (EA) energy demand and supply outlook for the coming decades. In this context, African energy demand is expected to rise from 24 GW to 150 GW by 2030. Figure 5(a) shows that Central Africa demand is 25 GW, Eastern Africa demand is 55 GW, North Africa demand is 318 GW, West Africa demand is 63 GW, and Southern Africa demand is 63 GW (150 GW). In energy, total household demand was 600 TWh in 2010 and 750 TWh in 2020 and will rise to 750 TWh in 2030 [21, 22], while productive

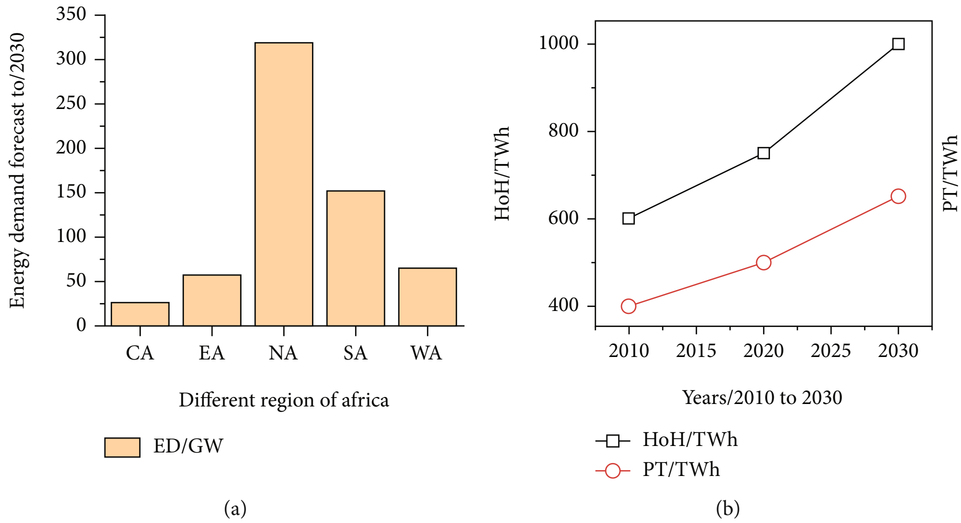


FIGURE 5: (a) Different regions of Africa. CA: central Africa; EA: east Africa; NA: north Africa; SA: southern Africa; WA: west Africa. (b) Household (HoH) and productive and transport (PT) sector energy demand.

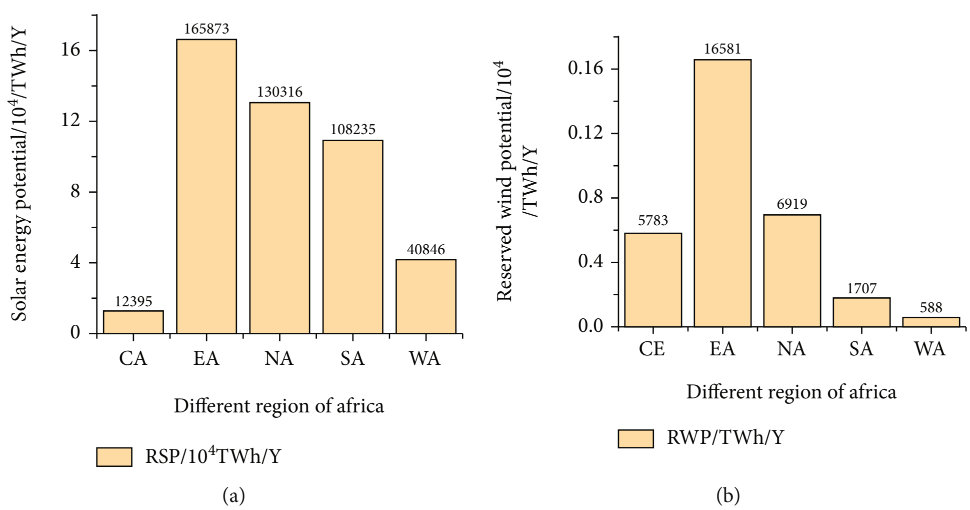


FIGURE 6: (a) Solar potential; (b) wind energy potential of different African regions per TWh/year from 2010 to 2030.

and transport sector energy demand was 400 TWh in 2010 and 500 TWh in 2020 and will rise to 650 TWh in 2030.

This implies that energy demand, as well as the productive and transportation sectors, are the most critical for Africa's long-term development. The overall estimation of massive green energy from various African regions shows that Africa has promising energy potential. Figures 5(a) and 5(b) show that household (HoH) energy demand has increased from 600 TWh to 1180 TWh, while productive and transportation (PT) energy demand has increased from 400 TWh to 650 TWh. As a result, household energy demand increased by 49.4%, while PT energy necessity increased by 38.5%.

Figure 6(a) depicts the overall solar energy potential in various African regions. For example, Central Africa (CA) has a 12,395 TWh/Y, East Africa (EA) has a 165,873 TWh/Y, Northern Africa (NA) has a 1,301,316 TWh/Y, Southern Africa (SA) has 108,235 TWh/Y, and Western Africa (WA) has a 40,846 TWh/Y. Figure 6(b) depicts wind energy in various African regions. In this context, Africa's total available solar and wind energy is far greater than its total energy demand [20–24]. East Africa (EA) estimates the ratio of available and demanding energy resources to be $3.01587 \times 10^7$ TW/Y for solar potential and $3.015 \times 10^6$ TW/Y for wind resources.

## 3. Methodology

In this study, we used the solar shortwave, radiation transfer model, and miniscale meteorological model for Weather Research Forecast (WRF) to assess the solar energy potential of different regions of Ethiopia. In addition, for wind energy assessment at different heights (10 m, 30 m, and 50 m) and wind energy density, we used spatial and temporal simulation and other sources such as a desk review of recently reported research and written documents of energy development organizations [25, 26].

## 4. Results and Discussion

*4.1. Solar Energy Potential in Ethiopia.* This section presents the monthly solar radiation density of Ethiopia as shown in Figure 7. The minimum irradiation reported was 1858 Wh/m$^2$/month in December, and the highest was 15,348 Wh/m$^2$/month in April. The maximum of 207,232 Wh/m$^2$/month in February increases to higher 255,147 Wh/m$^2$/month in May, as shown in Table 2. Furthermore, in both the mean value and St. Dev, the variation of solar radiation is approximately uniform throughout the year. This report provides Ethiopia with a huge solar energy potential for solar power investment and a profitable opportunity for investors [21, 25].

In addition, Figure 8 shows the average solar flux per unit area of different regions of Ethiopia. It shows a higher average flux in Tigray (246.48 W/m$^2$) at the area of 50.2 km$^2$, Amhara (240.34 W/m$^2$) at the area of 155 km$^2$, and Afar (239.9 W/m$^2$) at the area of 94.1 km$^2$, as shown in Table 3. Therefore, the flux density area ratio in Tigray (4.9) is almost twice that in the Afar region (2.5) and three times that in the Amhara region (1.5). This implies that the solar potential of the Afar region is higher than that of the other regions next to Tigray, even though it is only about 5% higher across the whole country, and that the Afar region is the best-running region for solar energy [22, 23].

Figure 9 shows the average annual solar radiation, in kW·h/(m$^2$·a), of two different periods: (a) 1980-1989and (b) 2000-2009 [10]. Figure 9(a) shows that the solar flux is between 2100 kW·h/(m$^2$·a) and 2150 kW·h/(m$^2$·a) in the range of 10°N to 14°N vs. 30°E to 40°E. And Figure 9(b) shows a flux distribution range of 2110 to 2240 kW·h/(m$^2$·a). The solar radiation of Central and West Ethiopia is low in comparison to the periods 1980-1989 and 2000-2009. Therefore, the average solar energy distribution is highest at the degrees from 8°N to 14°N and 38°E to 42°E in both periods.

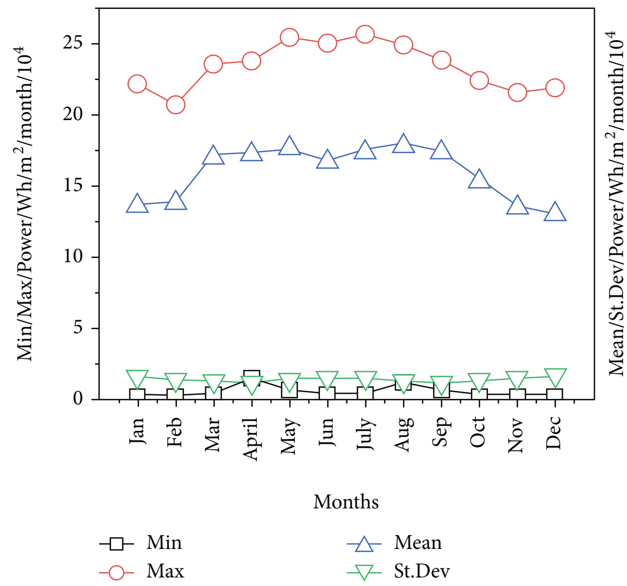


Figure 7: Monthly global solar radiations.

Table 2: Temporal monthly radiation in Ethiopia (Wh/m$^2$/month).

| Month | Min | Max | Mean | St. Dev |
|---|---|---|---|---|
| January | 1930 | 221,940 | 136,288 | 16,161 |
| February | 2148 | 207,232 | 138,439 | 13212 |
| March | 3646 | 236,328 | 170,906 | 12,501 |
| April | 15,348 | 238,981 | 172,893 | 11,899 |
| May | 6961 | 255,147 | 176,442 | 14,233 |
| June | 3286 | 250,390 | 167,735 | 14,906 |
| July | 4026 | 257,094 | 175,074 | 14,788 |
| August | 11,533 | 249,714 | 178,741 | 12,792 |
| September | 6624 | 239,322 | 174,338 | 12,143 |
| October | 2376 | 224,323 | 153,691 | 13,549 |
| November | 1912 | 216,207 | 135,489 | 15,351 |
| December | 1858 | 219,516 | 130,485 | 16,523 |

*4.2. Wind Energy Potential of Ethiopia.* Generally, the total wind potential of Ethiopia is estimated at 10 GW [17, 25]. Based on the spatial distribution of wind, power density is high in the central region of Ethiopia, the border region, the Afar region, and the Somali region. There is significant shear of wind power density at heights ranging from 10 m to 50 m as shown in Table 4. Wind energy density is 200 W/m$^2$ at a height of 10 m and an annual average speed of 5.6 m/s; wind density is 320 W/m$^2$ at a height of 30 m and an annual average speed of 6.5 m/s; and wind energy density is 400 W/m$^2$ at a height of 50 m and an annual average speed greater than 7 m/s. This result indicates that there is abundant wind energy in Ethiopia.

Figure 10(a) shows that wind power density increased from 100 W/m$^2$ to 1000 W/m$^2$, with a corresponding increase in annual average wind speed, Anu(V), from 4.4 m/s to 9.4 m/s at 10 m height in different wind energy classifications (Table 4). This indicates that wind power density in the range of 200 to 250 W/m$^2$ and its speed of 6 m/s at the fourth classification is suitable for wind power investment above or equal to 10 m height. Figure 10(b) shows an increase in wind density from 160 W/m$^2$ to 1600 W/m$^2$ at a height of 30 m with an increase in wind speed from 5.1 m/s to 11 m/s. This indicates that wind power density is higher than the range between 240 and 320 W/m$^2$ and its speed is higher than 6.5 m/s at the third class. Figure 10(c) shows that wind speed at 50 m and wind density have maximum values from 200 W/m$^2$ to 2000 W/m$^2$, and their corresponding wind speeds increased from 5.6 m/s to 11.9 m/s. This implies that both the 30 m and 50 m heights are good positions at the fourth class and above for grid-based wind power generation (Table 4).

Generally, Figures 10(a)–10(c) show that for heights ranging from 10 m to 50 m, the wind power density increased from 100 W/m$^2$ to 2000 W/m$^2$ with an increase in wind speed from 4.4 m/s to 11.9 m/s. Figure 10(d) shows the graph of the class of wind power density vs. the annual velocity of wind at heights of 10 m, 30 m, and 50 m. This indicates a wind speed increase as a class of

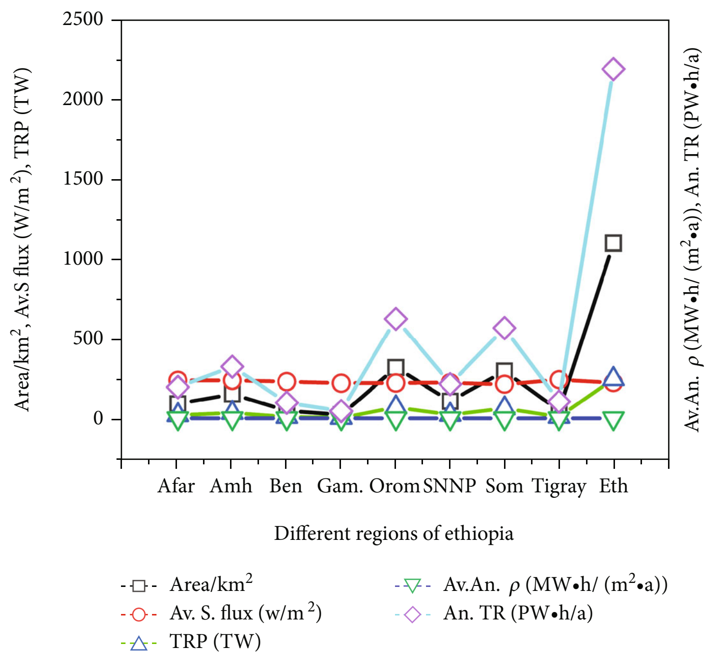


Figure 8: Annual total solar energy flux per unit area, solar average annual flux density (MW·h/(m$^2$·a)), and total reserve power in TW of different regions in Ethiopia.

Table 3: Solar energy resource in different regions of Ethiopia.

| Regions | Area (1000 km$^2$) | Av. S. flux (W/m$^2$) | TRP (TW) | Av. an. $\rho$ (MW·h/(m$^2$·a)) | An. TR (PW·h/a) |
|---|---|---|---|---|---|
| Afar | 94.1 | 239.9 | 22.57 | 2.102 | 198 |
| Amhara | 155 | 240.34 | 37.26 | 2.105 | 326 |
| Benishangul | 49.5 | 232.52 | 11.5 | 2.037 | 101 |
| Gambelia | 24.6 | 222.48 | 5.48 | 1.949 | 48 |
| Oromia | 320 | 223.96 | 71.66 | 1.962 | 628 |
| SNNP | 109.9 | 226.65 | 24.91 | 1.986 | 218 |
| Somali | 300.3 | 217.19 | 65.21 | 1.903 | 571 |
| Tigray | 50.2 | 246.48 | 12.38 | 2.159 | 108 |
| Ethiopia | 1,103.60 | 227.42 | 250.98 | 1.992 | 2199 |

Av. S. flux: average solar radiation flux; TRP: total reserve power; Av. an. $\rho$: average annual solar density; An. TR: average annual total reserve.

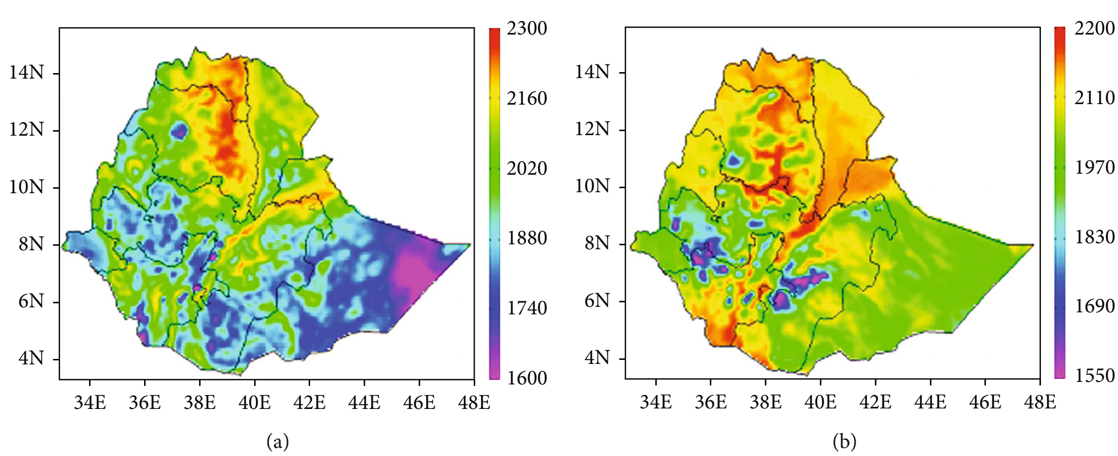


Figure 9: Average annual total solar radiation, kW·h/(m$^2$·a): (a) 1980-1989; (b) 2000-2009.

Table 4: Wind power density and wind speed at different heights at $h = 10$ m, $h = 30$ m, and $h = 50$ m; CWP$\rho$: classification of wind power density, $D$ (W/m$^2$), annual wind speed, and Anu(V) (m/s).

| CWP$\rho$ | At $h = 10$ m | | At $h = 30$ m | | At $h = 50$ m | |
|---|---|---|---|---|---|---|
| | $D$ (W/m$^2$) | Anu(V) (m/s) | $D$ (W/m$^2$) | Anu(V) (m/s) | $D$ (W/m$^2$) | Anu(V) (m/s) |
| 7 | 400-1000 | 9.4 | 640-1600 | 11 | 800-2000 | 11.9 |
| 6 | 300-400 | 7.0 | 480-640 | 8.2 | 600-800 | 8.8 |
| 5 | 250-300 | 6.4 | 400-480 | 7.4 | 500-600 | 8.0 |
| 4 | 200-250 | 6.0 | 320-400 | 7.0 | 400-500 | 7.5 |
| 3 | 150-200 | 5.6 | 240-320 | 6.5 | 300-400 | 7.0 |
| 2 | 100-150 | 5.1 | 160-240 | 5.9 | 200-300 | 6.4 |
| 1 | 100 | 4.4 | 160 | 5.1 | 200 | 5.6 |

CWP$\rho$: classification of wind power density.

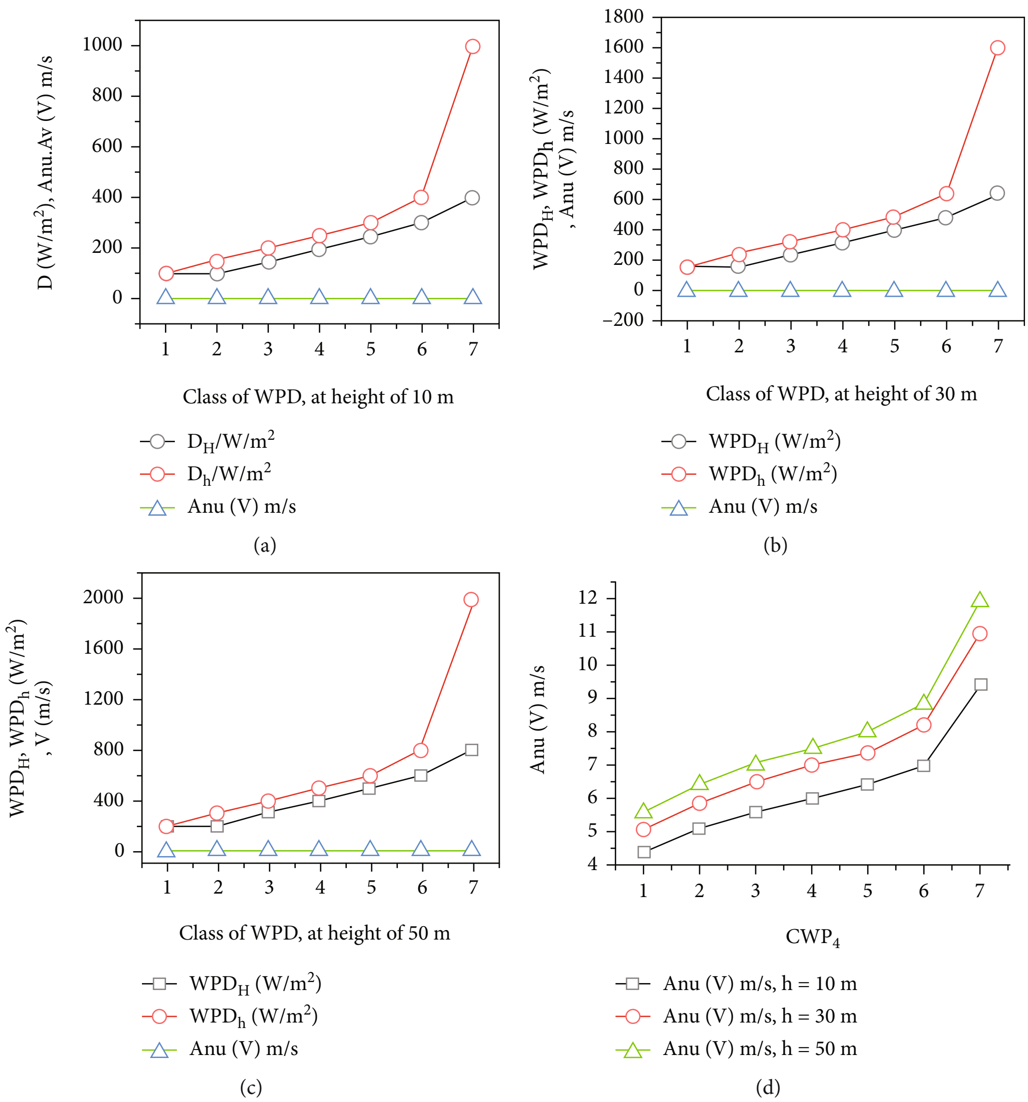


Figure 10: Wind power density and wind speed at different heights: (a) $H = 10$ m, (b) $H = 30$ m, and (c) $H = 50$ m, (d) Class of wind power density vs. annual (V) (m/s).

wind power density in central Ethiopia, the Afar region, and Somali region where wind power density reaches above class 4, and the annual average velocity is greater than 6 m/s at $h = 10$ m, 7 m/s at $h = 30$ m, and 7.5 m/s at $h = 50$ m. This shows that Ethiopia is suitable for grid-connected and small-scale off-grid wind power generation. Based on these data, the Afar region is also a promising region for wind power generation [10, 27].

*4.3. Solar Energy Potential in Afar Region.* The solar energy potential of western and northern Ethiopia, such as the Amhara region, Gambelia region, Tigray region, and Afar region, has the highest solar potential in Ethiopia, as shown in Table 3 [19, 24]. The average solar radiation distribution increased in the northern part and is more modern in central Ethiopia and west Ethiopia as shown in Figure 11. Furthermore, total solar energy distributions are indicated by overall average annual total solar radiation distributions. During that time, the south of central Ethiopia and west Ethiopia had more pronounced low-radiation zones in the time interval of 1990-1999. On the other hand, despite rising radiation levels in high-radiation zones between 2000 and 2009, as shown in Table 5 (Figure 11), solar radiation increased in the southeast, but there was no discernible low-radiation zone.

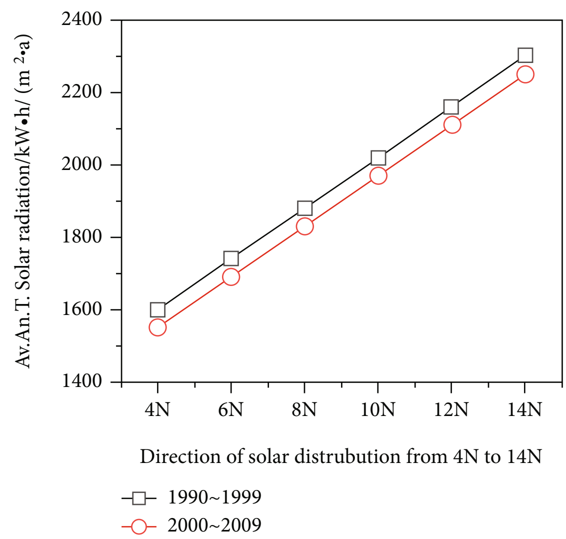


Figure 11: Average annual solar radiation distribution from 4°N to 14°N.

*4.4. Wind Energy Potential of Afar Region.* Geographically, the Afar region is located between latitudes of 11.45°N to 14°N and longitudes of 40°E and 42°E; both its wind speed and wind density are very high. Figure 10 displays the wind power density distribution in $W/m^2$ for various heights from 4°N to 14°N latitudes (Table 6).

The wind density distribution for both $H = 10$ and $H = 50$ m increased from 4°N to 14°N, as shown in Figure 12. For grid-based power generation, the wind density at height $H = 10$ m increased from 50 $W/m^2$ to 300 $W/m^2$ at 10°N to 14°N (Afar region), ranging from 200 $W/m^2$ to 300 $W/m^2$. However, the wind power density at height $H = 50$ m increased from 100 $W/m^2$ to 600 $W/m^2$, and 50 $W/m^2$ to 300 $W/m^2$, at 10°N to 14°N (Afar region), which is excellent for non-grid-based power generation (Table 6). According to the spatial distribution of wind speed, different heights demonstrate that speed is high in central Ethiopia and the border regions of Afar and Somali.

Figure 13 shows the estimated wind energy potential resource reserve and exploitable quantity of wind resources in Ethiopia and the Afar region at $h = 50$ m. It illustrated that potential exploitable wind energy resources are highest in the Somali region and lowest at the Southern Nations, Nationalities, and People's (SNNP) region. The Afar region has 57 GW exploitable and 200 GW reserved wind potential, which puts it in fourth place in Ethiopia's energy reserve, as shown in Table 7 [17]. This result indicates that the Afar region is also a potential wind resource area for the country, and wind energy could be a promising alternative energy source for the Afar region [28, 29]. Therefore, wind power densities and monthly wind speed is highest in both central Ethiopia and the border of the regions of Afar and the Somali. In most parts of central Ethiopia and west Ethiopia, wind power density is low, and grid-connected power generation is not supported.

Figure 14 shows the monthly average wind speed and wind power density reaching their highest value of 11.24 m/s and 1086.2 $W/m^2$, respectively, in July, as shown in Table 8. There was a significant increase from November to July. The corresponding wind speed increased from 5.77 m/s to 11.24 m/s [30, 31]. This high wind density and wind speed are evidence that there is rich wind energy potential in the Afar region. In particular, wind speed was lowest in April and highest in July. Therefore, it meets the requirements for having huge wind energy resources all over the country and the Afar region [32, 33].

*4.5. Geothermal Energy of Afar Region.* Geothermal energy uses heat from the earth's internal geologic processes in order to produce electricity or provide heating. It is strong in the eastern part of Africa. Ethiopia is among the countries with good geothermal potential in Africa. Ethiopia is gifted with a significant amount of geothermal energy, which is spread along the Danakil Depression and Rift Valley. According to previous studies, Ethiopia has an exploitable geothermal potential of approximately 5000 MW. However, this is unexploited potential at the present time, and for now, only a pilot project of 7.5 MW has been installed at Aluto Langano and another pilot project is under construction at Tendaho Dubti around 10 MW [28, 29, 34, 35]. As a result, the Afar region is the most promising geothermal energy source in the world in terms of high geothermal resources for the region's and Ethiopia's sustainable development [36, 37].

*4.6. Biomass Energy Potential of Afar Region.* According to the recent energy report, more than 70% of sub-Saharan Africa's total energy consumption is from solid biomass energy sources. Wood fuels such as straw, charcoal, and dried animal products used as cooking fuel account for nearly 90% of household energy consumption. In this perspective, Ethiopia has a significant amount of biomass energy resources. According to recent research report the estimated national woody biomass stock, dead wood, and homestead tree yields were around 1149 million tons with an annual yield of 50 million tons per year 2000, as was predicted by the Woody Biomass Inventory and Strategic Planning Project [33, 38]. Due to Ethiopia's higher rate of population growth, biomass energy resources are being exhausted quickly. However, the Afar region is one of the hottest and driest places in Ethiopia, with a pastoralist population living in changing environmental conditions, and

Table 5: Annual solar radiation distribution (W/m$^2$) at different degrees from 4°N to 14°N.

| Direction<br>Time period | 4°N | 6°N | 8°N | 10°N | 12°N | 14°N |
|---|---|---|---|---|---|---|
| 1900-1999 | 1600 | 1740 | 1880 | 2020 | 2160 | 2300 |
| 2000-2009 | 1550 | 1690 | 1830 | 1970 | 2110 | 2250 |

Table 6: Distribution of wind power density (W/m$^2$).

| Direction<br>Time period, $H$ | 4°N | 6°N | 8°N | 10°N | 12°N | 14°N |
|---|---|---|---|---|---|---|
| 1980~2009, $H = 10$ m | 50 | 100 | 150 | 200 | 250 | 300 |
| 1980~2009, $H = 50$ m | 100 | 200 | 300 | 400 | 500 | 600 |

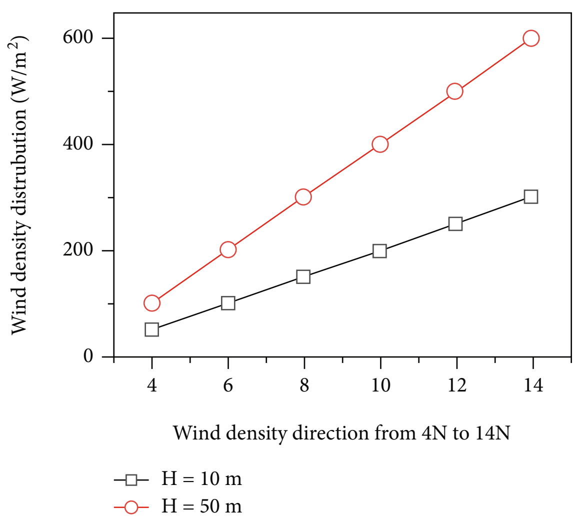


Figure 12: Wind power density distribution from 4°N to 14°N.

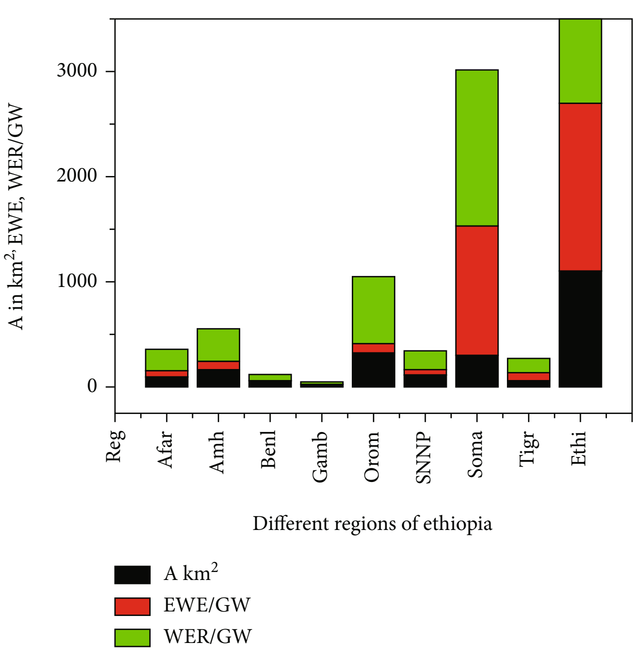


Figure 13: Wind energy resource of Afar region and Ethiopia. A: area; EWE: energy of wind potential; WER: wind energy reserve.

Table 7: Wind resource in Afar region and different regions of Ethiopia at $h = 50$ m.

| Regions | Area (1000 km$^2$) | EWE (GW) | WER (GW) |
|---|---|---|---|
| Afar | 94.1 | 57 | 200 |
| Amhara | 155 | 86 | 310 |
| Benishangul | 49.5 | 0 | 60 |
| Gambelia | 24.6 | 0 | 20 |
| Oromia | 320 | 87 | 640 |
| SNNP | 109.9 | 53 | 179 |
| Somali | 300.3 | 1231 | 1490 |
| Tigray | 50.2 | 83 | 140 |
| Ethiopia | 1103.60 | 1599 | 3030 |

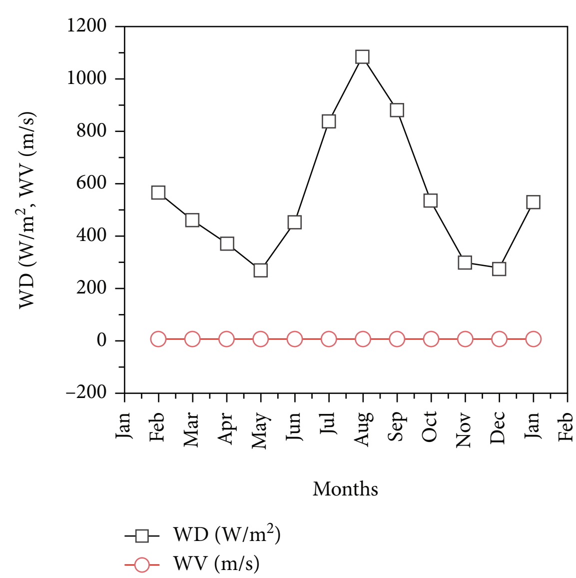


Figure 14: Monthly wind density and speed of the Afar region.

there is no research report on the Afar region's biomass energy potential [39–41].

*4.7. Hydropower Energy Potential of Afar Region.* Ethiopia is gifted with a huge amount of water potential. Ethiopia is located in the Horn of Africa and is among the fastest-

TABLE 8: Monthly wind density and speed of Afar region.

| Months | Wind density (W/m$^2$) | Wind speed (m/s) |
|---|---|---|
| Jan | 565.9 | 8.11 |
| Feb | 460.3 | 7.98 |
| Mar | 372.7 | 7.12 |
| Apr | 270.1 | 5.77 |
| May | 453.5 | 7.51 |
| Jun | 840.1 | 10.34 |
| July | 1086.2 | 11.24 |
| Aug | 883.3 | 10.13 |
| Sep | 535.3 | 8.48 |
| Oct | 301.1 | 6.11 |
| Nov | 274.8 | 5.69 |
| Dec | 533.3 | 7.96 |

developing nations on the continent [42]. Ethiopia has enormous hydropower potential (approximately 45,000 MW per year) [43, 44], but only about 8.5% of its capacity is used. Currently, the following different hydropower projects are active in Ethiopia, Gilgel Gibe I dam (183 MW) [45], Gibe II dam (420 MW) [46], Gilgel Gibe III dam (1870 MW) [47], Beles Hydroelectric Power Plant (460 MW) [48], and Tekeze Hydropower (300 MW) [49]. Recently, the world-class Grand Renaissance Dam (6000 MW) has been on progress [49]. Despite this, there is no research report on hydropower energy potential in the Afar region [29, 35].

## 5. Conclusion and Recommendations

Recently, Ethiopia has become a leading African nation in the development of the energy sector due to the construction of the Grand Ethiopian Renaissance Dam (GERD). However, only about 0.2% of electrification was powered by green energy sources. The study's findings confirm that the Afar region has enormous potential for green energy, specifically solar, wind, and geothermal, but that nearly all of that potential is still untapped. Moreover, the study indicates that the Afar region is gifted with a monthly average daily global solar radiation intensity of 5.58–6.66 kWh/m$^2$, and the average wind speed increased from 5.69 to 11.24 m/s. Therefore, green energies are an absolutely promising energy alternative for power generation of the Afar region.

On the basis of the research findings, the following recommendations are made:

(i) Different universities and government energy sectors should be motivated and trained to use solar and wind energy

(ii) Motivational awareness programs should be conducted for the use of solar and wind energy

(iii) Universities and academic institutions should provide technical training programs to teach energy device operation and maintenance

## Data Availability

Data used for research is embedded within the manuscript.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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