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COMPARATIVE SYSTEM ANALYSIS OF RENEWABLE AND NUCLEAR ENERGY TAKING INTO ACCOUNT ETHIOPIAN REGIONAL FEATURES

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ABSTRACT

Among installed capacity of renewable energy technologies in Ethiopia, hydropower takes the largest part. Looking to other renewable technologies that enable a low carbon energy system has a great role to meet the plan of energy needs in the country. This paper presents renewable energy resources potential of country, and review of technologies used for them and their usage in energy grid. Prospects for the use of Russian-made nuclear reactors have been assessed for construction of nuclear plant in the region. The paper also presents review results of energy costs of renewable technologies and combined gas turbine with financial cost parameters for assessing energy technologies: overnight capital cost, operating costs and levelized cost of electricity (LCOE). The findings suggest that wind energy has the lowest energy costs.

Keywords: *Energy costs, levelized Cost of Electricity, Renewable Technologies,*

I. INTRODUCTION

Ethiopia is located in the eastern part of Africa between 3° to 15° north and 33° to 48° east. With a surface area of 1.1 million square kilometers, it is the third largest country in Africa. It is the second most populous country in Sub Saharan Africa with an estimated population of about 100 million, which is mostly distributed in northern, central and southwestern highlands.

Renewable energy resources in Ethiopia, with the exception of biomass, have not been actively incorporated into the national energy program. Apart from very few donor driven and project-based markets there has been hardly any development in the utilization of renewable energy resources and dissemination of such technologies. Knowledge of the exploitable potential of the renewable resources and identification of potential regions for development will help energy planners to incorporate the resources as alternative means of supplying energy by conducting a more accurate techno-economic analysis which leads to more realistic economic projections.

Ethiopia is endowed with abundant renewable energy resources and has a potential to generate over 60,000 MW of electric power from hydroelectric, wind, solar and geothermal sources, currently it only has approximately 2,300 MW of installed. The targets for increasing generation capacity to 10,000 MW established under the first iteration of the growth and transformation plan (GTP) will be met by completion of two major hydro power plants in 2017 and 2018. The current GTP has a new target to increase generation capacity to over 17,000 MW by 2020, with an overall potential of 35,000 MW by 2037, which would help sustain Ethiopia's continued economic growth and enable it to become a regional renewable energy hub in East Africa [1].

To achieve these aggressive power generation targets with effective economy, considering generating cost of energy and selecting appropriate location for the energy generation plant is one of studying areas for the energy plan. This paper tried to show the cost effective renewable power generation plant technologies based on levelized cost of energy (LCOE) comparative system analysis.

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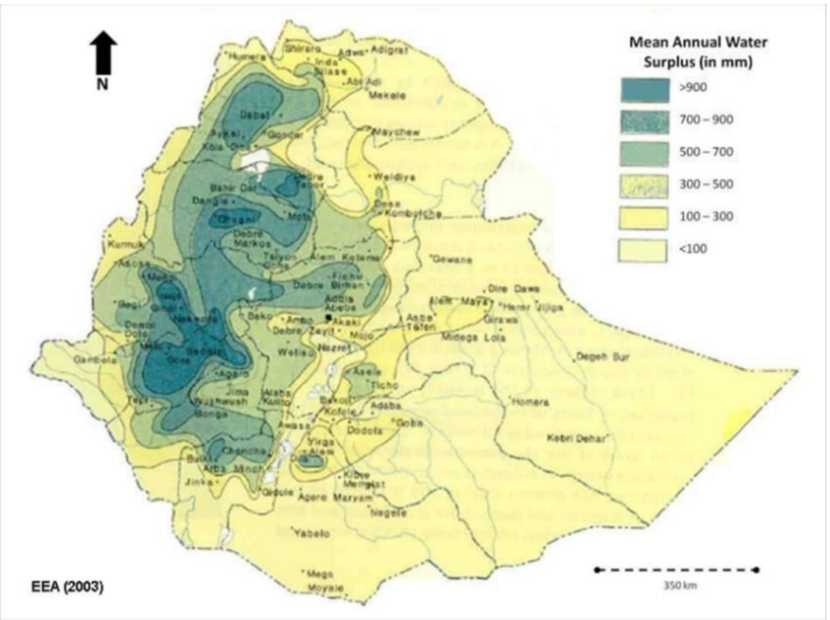
II. RESOURCES OF RENEWABLE ENERGY IN ETHIOPIA AND TECHNOLOGIES IN ENERGY SYSTEM

Hydropower resources

Ethiopia's plentiful hydropower resources are distributed in nine major river basins and their innumerable tributaries, which is estimated to generate an economically affordable energy of about 45, 000 MW. So far very little percentage (less than 5%) of the vast potential has been exploited [2].

Some 300 hydropower plant sites in the whole eight river basins of the country with a total technical power potential of 159,300 GWh/year have been identified. Out of these potential sites, 102 are large scale (more than 60 MW) and the rest are small (less than 40 MW) and medium scale (40-60 MW) hydropower plant sites

Like all other natural resources, Ethiopia's hydro resources are unevenly distributed over its land mass. Generally speaking, the amount of rainfall and topographic conditions suitable to hydro-electricity generation, i.e., head decrease as one moves away from west to east until it gets totally arid, flat desert-type in the Ogden lowlands. While rainfall is in relative abundance in the western and southern parts of the country, it gets moderate in the northern highlands and central plateau (see fig. 1). Thus, it could be argued that the distribution of Ethiopia's hydro resource is in contrast with that of its wind energy resource, since the former decreases while the latter increases as we descend to the eastern lowlands. And the opposite is true in the western, central and south western highlands [3].



EEA (2003)

Figure 1: Mean annual water surplus in Ethiopia

Solar Energy Resources

Ethiopia located near the equator its solar resource is obviously of significant potential. The responsible organization for collection and documentation of solar resource data in Ethiopia is the National Meteorological Service Agency (NMSA). Solar resource data including the daily irradiance and sunshine hours for some areas in Ethiopia have been collected and documented by various organizations such as the NMSA, Ethiopian Civil Aviation Authority, and, Food and Agricultural Organization (FAO) of Rome. Further solar resource potential estimation analysis on a national level based on measured data and theoretical methods was carried out by CESEN-ANSALDO Group in the mid-1980s. As an outcome of this study by CESEN, a solar energy map with iso-energy curves for yearly average radiation on a horizontal surface was developed for the first time. Lacking suitable direct measurements, the estimation of solar radiation of Ethiopia by CESEN was limited to measurements of sunshine hours and cloud cover.

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Data on cloud covers were available only for 12 stations and the instruments used to measure cloud cover (only 20 stations for which data was available) allowed only very course estimates of incident radiation [4].

In the absence of sufficient data on global radiation and sunshine hours, the total radiation on a particular area is usually estimated based on climatic and geographical analogy of other neighboring areas for which data is available. Following this, the estimation of total radiation by CESEN in areas with a very low density of ground stations, extrapolation was made to cover wider areas leading to uncertainties which can be considerably larger. It is also noted by CESEN that the iso-energy curves in areas with very low density of stations and near the boarders of the country must be considered less reliable. According to CESEN, the annual average daily radiation in Ethiopia reaching the ground is 5.2 kWh/m2/day. The minimum annual average radiation for the country as a whole is estimated to be 4.5kWh/m2/day in July to a maximum of 5.55kWh/m2/day in February and March.

The values vary seasonally with a location 4.25 kWh/m2/day in the extreme western lowlands to 6.25 kWh/m2/day in Adigrat area, Northern part of Ethiopia [5].

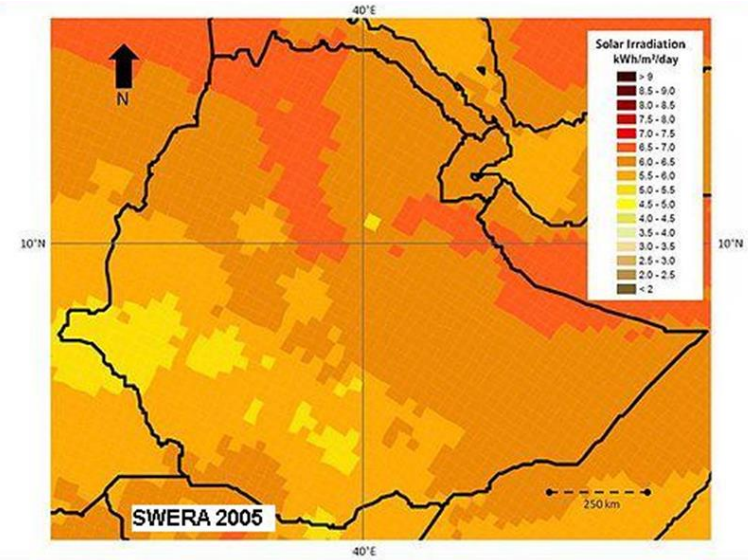


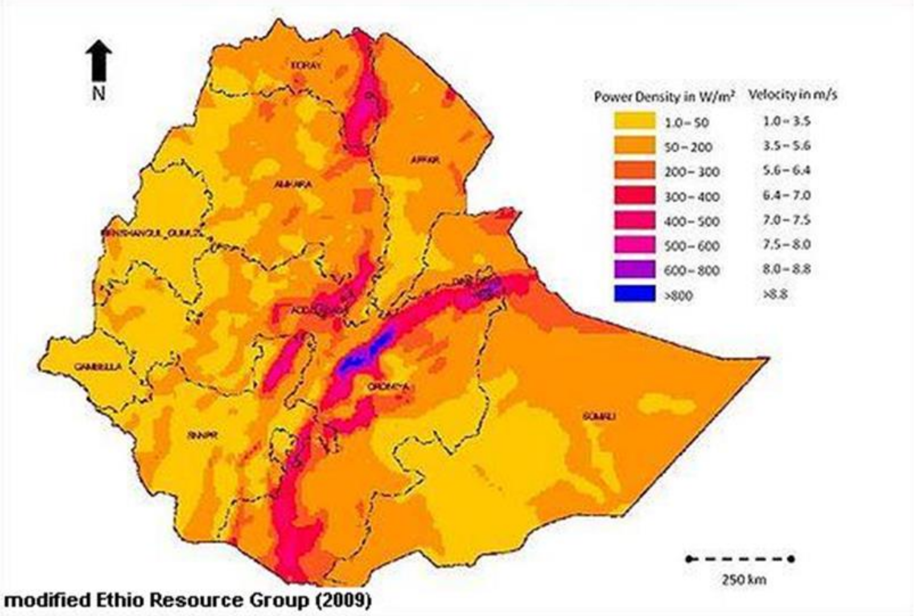
Figure 2: Solar irradiation in Ethiopia

Wind Energy Resources

Ethiopia has good wind resources with velocities ranging from 7 to 9 m/s. The total wind energy resource reserve of 3,030 GW and the potential exploitable quantity of is 1,350 GW [5].

Based on wind data collected by Ethiopian National Meteorological Services Agency (NMSA) for more than 40 years, Ethiopia's wind energy potential is considerable and the wind energy is highly variable over the terrain mainly as a function of topography of the country. Pockets of areas with high wind velocities of up to 10 m/s are distributed throughout the Eastern half of the country, including the western escarpment of the Rift Valley.

Seasonal and daily variation in wind velocity is also considerable; wind velocity is higher between early morning and mid-day and in terms of seasonal variation, in the highland plateau zone there are two peak seasons – March to May and September to November; and in the eastern lowlands wind velocity reaches its maximum between May and August. In most of these places, maximum wind velocities are 3 to 4 times greater than the minimum. Medium to high wind speed of 3.5 to 6 m/s exists in most Eastern parts and central Rift Valley areas of the country. Perhaps due to their mountainous terrain and land use/land-cover type, most western and north-western parts of the country have generally low wind velocity.



modified Ethio Resource Group (2009)

Figure 3: Annual mean wind in Ethiopia

Geothermal Energy Resources

Ethiopia's geothermal resources are distributed along the Rift valley where temperatures of 50 – 300°C prevail in a depth of 1,300 – 2,500 m. These resources are scattered throughout the Ethiopian Rift valley and in the Afar Depression, which are both part of the Great East African Rift System. The Ethiopian rift extends from the Ethiopia-Kenya border to the Red Sea in a NE direction for over 1 000 km within Ethiopia, and covers an area of 150,000 km2. Based on the results of the investigations, Ethiopia could possibly generate more than 1000 MW of electric power from geothermal resources alone. This is substantially in excess of its annual requirement of around 780 MW from all energy sources for the current Inter connected and Self Contained Systems [6].

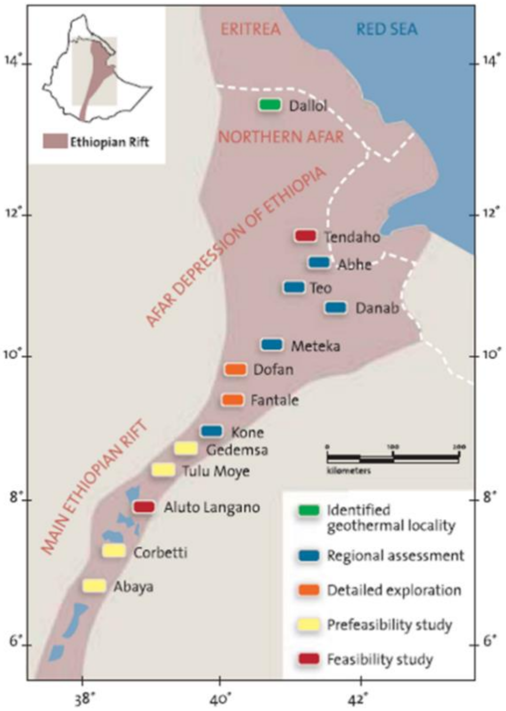


Figure 4: Geothermal resources in Ethiopia

Prospects of Nuclear power plant

The progressive development of industry zone in the country asks lot energy. For this challenge of energy scarcity, finding other types of energy plant which can fit the demand energy and establishing non-pollutant energy source like nuclear energy are necessary. In assessing of the prospect use of Russian-made nuclear reactors or foreign analogues for the construction of nuclear power in the region, looking to the possibility of using appropriate fuels, the possibility of ensuring safe operation and handling of nuclear materials and the possibility of providing stations with personnel are the factors discussed in this study.

Availability of uranium

Ethiopia reported limited uranium exploration activity in the Red Book in 1979, 1983 and 1986 but has not been active in this program since. Uranium exploration activities began in the 1950s and information on airborne radiometer surveys and relevant ground prospecting during 1954-1964 are provided in a number of diverse sources [7]. As a result of these early exploration activities, many localities are reported to indicate uranium-bearing mineral manifestations, though their specific locations are not well presented and recognized. Between 1968 and 1970, airborne geophysical surveys in southern and western Ethiopia were conducted as part of the United Nations Development Program (UNDP).

Accordingly 13 anomalies in southern Ethiopia, 8 of which were checked by ground survey and 6 anomalous bodies out of 36 in western Ethiopia were investigated and none were found to support the existence of proper uranium mineralization. In addition to this, the 1993-1994 airborne geophysical survey of southern basement rocks under the Ethiopia-UNDP program, as well as a similar type of survey by the Ethio-Nor Program in western Ethiopia in 1997-2001, failed to identify significant radiometric anomalies related to radioactive mineral resources. Based on an interest in diversifying energy resources, the Ethiopian government initiated in 2006 the Uranium Resource Exploration Project. However, these activities only detected some radiometric anomalous spots related to localized pegmatite bodies hosting only minerals accessory to uranium. Since recent uranium exploration in Ethiopia is based on limited information and little knowledge, the efforts to discover uranium deposits in all favorable geological terrains in the country need a highly experienced expertise and capacity-building approach that overcomes past difficulties in exploration for uranium resources. Ethiopia does not currently produce uranium. However, efforts are being made in order to define possible targets of interest. In the first quarter of 2010, the Geological Survey of Ethiopia (GSE) signed a Uranium Resource Assessment Agreement with Russian Geological Survey, Zarubezhgeologia (JSC), and accordingly a specialist has been employed for a specific period to conduct an overall assessment of favorable geological settings with uranium mineral resource potential [8].

Previous and current exploration detected insignificant radiometric anomalies that are mainly related to variation in the background values of rocks or accessory minerals in localized targets. With demand for a capacity-building program to solve challenges associated with the identification of uranium provinces, Ethiopia strongly encourages uranium mineral exploration in order to diversify the energy mix. In 2011, the assessment of possible uranium related areas has been launched under an expert assisted program with the support of radiometric equipment from sister countries. Co-operative assessment activities have been continuing. This work is concentrated on characterizing U-enriched granitites that could be possible uranium ore sources to help narrow the search in surrounding areas for possible uranium concentrations of economic interest. In addition to this, proposals for an airborne survey and for the application of remote sensing technology are being pursued under the co-operation program with sister institutions from abroad.

Technologies in Energy System.

Energy conversion of renewable energy sources with current technology that would offer dependable and efficient electricity facility. Energy developers, investors and policy makers face a future that implicitly involves technological and financial. Although, renewable energy technologies potentially have a lower risk profile than conventional energy sources because they are disconnected from fossil fuel prices and entail considerable technological [9].

In hydropower technology, water pressure is converted by hydro turbines into mechanical shaft power. The mechanical shaft power can be used to drive an electrical generator or other machinery [10]. The available power is directly proportional to the product of pressure head and volume flow rate. Generally, the hydraulic power P (KW) and the corresponding energy E (KWh) over an interval of time Δt(h) are, $Po = \rho gQH$, $E = \rho gQH\Delta t$. Where ρ is density of water (kg/m^3) and g is acceleration due to gravity (m/s^2) [10, 11].

Solar technologies of conversion energy from sunlight into electricity, either directly using photovoltaics (PV) or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for fulfilling heat requirements up to 300 ^{0}C at 20 bar pressure in industries, and for electric power production. Two categories include Concentrated Solar Thermal (CST) for fulfilling heat requirements in industries, and Concentrated Solar Power (CSP) when the heat collected is used for power generation. Photovoltaic cells convert light into an electric current using the photovoltaic effect which is the phenomenon of physical and chemical property [12]. Traditional single-crystalline silicon (Si) solar modules are made with silicon cells, are usually flat-plate, and generally are the most efficient solar modules with Electrical Efficiency Range (14% to 19%). Multi-crystalline Si modules are a similar technology, but may be slightly less efficient with Electrical Efficiency Range (13% to 17%). A third type of module technology, called thin-film, is made from amorphous Si or a thin layer of non-silicon materials, such as cadmium telluride (CdTe) or copper indium gallium dieseline (CIGD) with Electrical Efficiency Range (6% to 11%) [13]. PV-T technology is intended to increase the amount of solar energy collected from a solar energy system by combining the PV and solar thermal panels into a single system of collectors. The thermal collector (absorber) is attached to the back of an off-the-shelf PV module. The sun does not hit the thermal collector directly; instead the solar energy that is not converted into electricity by the PV panel can be collected as useful heat by the solar thermal collector. This increases the overall efficiency of the system [14]. As a renewable energy technology, the photovoltaic/thermal (PVT) hybrid system technology with the correct use of PVT collector, (rather than PV) is expected to first become competitive with the conventional power generation [15].

Wind turbines convert the wind's kinetic energy into electrical power with horizontal axis and vertical axis types of turbine. The power of the wind(Po) that flows at speed V through an area A is ρAV, which is proportional to the air density ρ, the intercepting area A and the velocity V to the third power. $P = ½ ρAV^3$ (W) where; ρ = air density (kg/ m^3), V = wind speed (m/s). The air density is a function of air pressure and air temperature, which both are functions of the height above sea level [16]. Horizontal Axis Wind Turbine with three bladed turbines is highly developed and used all over the world. The recent Research and Development has shown that the Vertical Axis Wind Turbine is more economical and efficient in respect of using land. To maintain 90% of the performance of isolated horizontal axis wind turbines, the turbines in a horizontal axis wind turbine farm must be spaced 3–5 turbine diameters apart in the cross-wind direction and 6–10 turbine diameters apart in the downwind direction. In such cases, it is found that by using vertical axis wind turbine instead of horizontal axis wind turbine on the same land area, it is possible to produce more than 10 times of wind energy. In the future vertical axis wind turbines can be more appropriate replacement of horizontal axis wind turbine [17]. Within the last three decades, the wind turbine size has been enlarged around 10–12 times while the unit capacity of wind turbine developed from 100 kW to 2MW. It is expected that in the near future the wind turbine capacity can be increased up to 10–12MW [17, 28]. The current offshore wind turbines in operation typically have three-bladed horizontal axis, yaw-controlled, active blade pitch to feather controlled, upwind rotors whose diameter can range from 65 to 130m and capacity is nominally between 1.5 MW and 5MW [18].

Geothermal power is power generated by geothermal energy that contained as heat in the Earth's interior. A technology in geothermal energy is used in three main ways: electricity generation, direct heating, indirect heating and cooling via geothermal heat pumps [19]. These three processes use high, medium, and low temperature resources, respectively. Geothermal energy is abundant and renewable, but only a small fraction can currently be converted commercially to electricity and heating value with today's technology. The words 'advanced geothermal technologies' often brings-up the term "hot dry rock" or the heat mining concept known as "enhanced geothermal systems," or EGS. This technology is only one of several emerging geothermal technologies tied to advances in subsurface tools and methodologies that could make production of energy possible from an expanded range of geothermal resources based on the long term effects on the life of the reservoir [20]. Because, potential of a geothermal reservoir during its lifetime depends on the reservoir temperature, production flow rate, fluid properties, and injection and extraction temperature. This can be mathematically expressed as: $\int_{t_b}^{t_a} Q(t) * \Delta h(T_I, T_E, t)dt$. Where: E = Potential of the geothermal reservoir, Q = Production flow rate, ta = Starting time of the reservoir, tb = Application abandonment time, Δh = Difference in the enthalpy between the injected temperature and the extracted temperature, TI = Injection temperature of the cold water, TE = Extraction temperature of hot water [21].

Nuclear energy is produced when an atom's nucleus is split into smaller nuclei by the process called fission. The fission of large atoms, such as Uranium 235 and Plutonium 239, produces a great deal of energy. In fact, the fission of 1 gram of Uranium 235 produces the same amount of energy as the combustion, or burning, of 3 tons of coal. The energy produced by the fission of uranium or plutonium can be harnessed to produce electricity. Unlike a traditional coal-burning power plant, a nuclear power plant uses the energy, or heat, produced by the fission of Uranium, rather than the burning of coal, to heat water into the steam required to turn the turbines that power electric generators.

Usage in Energy Grid

Energy generated by the renewable sources can feed local loads and the surplus power can be transferred to the grid-connected (GC) with the use of power electronics converter or can operate stand-alone (SA) mode. The quality of electrical power transfer between renewable energy sources and grid depends on the quality of voltage or current [22]. The voltage and current fed by the converter should be synchronized to grid with Harmonics level defined by Institute of Electrical and Electronics Engineers (IEEE) and International Electro technical Commission (IEC) standard. The integration of renewable source requires proper power control that plays important role for system efficiency and required output of the system. The available power from these renewable energy sources can be optimize and maximize by significant control of the system. Some renewable energy system may require power tracking control to track the maximum power point as in case of PV (Photovoltaic), wind power generating units [22,23].

Control components like switches to disconnect system from the grid in the event of a power surge or power failure, and power conditioning equipment that ensure as the power exactly matches the voltage and frequency of the electricity flowing through the grid are addressing safety and power quality of grid connection. The Institute of Electrical and Electronics Engineers (IEEE) has written a standard that addresses all grid-connected distributed generation including renewable energy systems. IEEE 1547-2004 provides technical requirements and tests for grid-connected operation [24]. Underwriters Laboratories (UL) has developed UL 1741 to certify inverters, converters, charge controllers, and output controllers for power-producing stand-alone and grid-connected renewable energy systems. UL 1741 verifies that inverters comply with IEEE 1547 for grid-connected applications.

The National Electrical Code (NEC), a product of the National Fire Protection Association, deals with electrical equipment and wiring safety. Although states and power providers are not federally mandated to adopt these codes and standards, a number of utility commissions and legislatures now require regulations for distributed generation systems to be based on the IEEE, UL, and NEC standards [24].

In a grid-connected power system the grid acts like a battery with an unlimited storage capacity. So it takes care of seasonal load variations. As a result of which the overall efficiency of a grid-connected system will be better than the efficiency of a stand-alone system, as there is virtually no limit to the storage capacity, the generated electricity can always be stored.

Stand-alone systems produce power independently of the utility grid; hence, they are said to stand-alone. These are more suitable for remotest locations where the grid cannot penetrate and there is no other source of energy. Stand-alone systems comprise the majority of photovoltaic installations in remote regions of the world because they are often the most cost-effective choice for applications far from the utility grid. The stand-alone systems suffer from innate disadvantages like low capacity factor, excess battery costs and finite capacity to store electricity forcing to throw away the extra energy generated [25].

III. RESULTS AND DISCUSSION

Levelized Cost of Energy

A levelized cost of energy (LCOE) calculation ascribes all future costs to the present value, resulting in a present price per unit energy value ($/MWh) [26]. For electrical energy storage systems, the LCOE provides a single levelized price that incorporates both the energy capacity costs ($/MWh) and the power costs ($/MW) over the life of the facility. In addition, the LCOE provides a useful metric for comparison between technologies that may have different energy capacities, power capabilities, capacity factors, efficiencies, financing terms, incentives, or numerous other costs.

The calculation of the LCOE is based on the equivalence of the present value of the sum of discounted revenues and the present value of the sum of discounted costs. Another way of looking at LCOE is that it is the electricity tariff with which an investor would precisely break even on the project after paying debt and equity investors, after accounting for required rates of return to these investors. This equivalence of electricity tariffs and LCOE is based on two important assumptions: The first is the real discount rate r used for discounting costs and benefits is stable and does not vary during the lifetime of the project under consideration. These rates should not be seen as being applicable to particular projects but as a method to compare the costs of various technologies across regions. The second is the electricity tariff, PMWh, is stable and assumed not to change during the lifetime of the project. All output, at the assumed capacity factor, is sold at this tariff. (Note that this is not necessarily the price at which the electricity will be sold once the plant is producing.)

$$\Sigma PMWh * MWh * (1+r)^{-t} = \Sigma[(Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t) * (1+r)^{-t}] \qquad (1)$$

Where the different variables indicate:

- $PMWh$ = The constant lifetime remuneration to the supplier for electricity;
- MWh = The amount of electricity produced in MWh, assumed constant;

- $(1+r)^{-t}$ = The discount factor for year t (reflecting payments to capital);
- $Capital_t$ = Total capital construction costs in year t;
- $O\&M_t$ = Operation and maintenance costs in year t;
- $Fuel_t$ = Fuel costs in year t;
- $Carbon_t$ = Carbon costs in year t;
- D_t = Decommissioning and waste management costs in year t.

The above equation (1) expressing that the equality between the present value of the sum of discounted revenues and the present value of the sum of discounted costs, including payments to capital providers. The subscript t denotes the year in which the sale of production or the cost disbursement takes place. The summation extends from the start of construction preparation to the end of dismantling, which includes the discounted value at that time of future waste management costs. All variables are real, i.e. net of inflation. On the left-hand side one finds the discounted sum of benefits and on the right-hand side the discounted sum of costs [39].

Because PMWh is a constant over time, it can be brought out of the summation, and the above equation can be transformed into

$$LCOE = PMWh = \frac{\Sigma[(Capital_t + O\&M_t + Fuel_t + Carbon_t + D_t) * (1+r)^{-t}]}{\Sigma \mathrm{MWh}(1+r)^{-t}}$$

Where this constant, PMWh, is defined as the levelized cost of electricity (LCOE).

Energy cost of generating technologies review

Costs are calculated at the plant level, and therefore do not include transmission and distribution costs. Similarly, the LCOE calculation does not capture other systemic costs or externalities beyond CO2 emissions. The analysis within this study is based on large scale hydro plant, a solar photovoltaic (PV) plant, concentrated solar power plant, onshore wind plant, a geothermal plant, nuclear power plant and a combined cycle gas turbine plant.

Table 1. Levelised cost of electricity for hydropower plants in Ethiopia

Technology	Capital costs USD/KW	O&M costs USD/KW	Fuel, waste & carbon costs USD/KW	LCOE Cents/KWh	Simple LCORE Cents/KWh
Gilgel Gibe III	855.61	53	0.00	0.2	2.4
Beles Power Station	1265.22	53	0.00	0.2	2.9

Table 2. Levelised cost of electricity for solar PV plants

Technology	Net capacity (MWe)	Capacity factor (%)	Investment cost USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
PV–residential rooftop	0.005	11	190.01	33.21	223.23
PV–commercial rooftop	0.5	11	137.16	23.98	161.13
PV–large, ground-mounted	5	11	108.23	18.92	127.14

Table 3. Levelised cost of electricity for solar thermal plants

Technology	Net capacity (MWe)	Capacity factor (%)	Investment cost USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
Thermal(CSP) – 6hrs storage	250	34	95.68	17.38	113.06
Thermal(CSP) – 12hrs storage	250	55	81.48	13.88	95.36
Thermal (CSP) – molten salt storage	92	60	138.30	53.78	192.08

Table 4. Levelised cost of electricity for wind turbine plants

Technology	Net capacity (MWe)	Capacity factor (%)	Investment cost USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
Onshore wind (South Africa)	100	34	87.39	13.86	101.93
Onshore wind (China)	50	26	49.73	9.76	59.92

Table 5. Levelised cost of electricity for geothermal plants

Technology	Net capacity (MWe)	Capacity factor (%)	Investment cost USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
Geothermal (Italy)	20	92	62.30	18.20	80.87
Geothermal (Turkey)	24	90	16.28	100.00	116.33

Table 6. Levelised cost of electricity for prospect nuclear power plants

Technology	Net capacity (MWe)	Investment cost USD/MWh	decommissioning costs USD/MWh	Fuel and waste costs USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
Gen III projects (Belgium)	1,000-1,600	60.09	0.08	10.46	13.55	84.17
LWR (Slovak Republic)	2 x 535	59.85	1.50	12.43	10.17	83.95
ALWR (United Kingdom)	3,300	68.42	0.52	11.33	11.00	77.71
ALWR (China)	1,250	30.92	0.04	9.33	7.32	47.61

Table 7. Levelised cost of electricity for natural gas plants

Technology	Net capacity (MWe)	Investment cost USD/MWh	Carbon cost USD/MWh	Fuel costs USD/MWh	O&M costs USD/MWh	LCOE Cents/MWh
CCGT (Korea)	396	11.29	10.27	98.97	5.55	126.08
CCGT (France)	575	11.37	10.56	68.99	6.25	97.21
CCGT (New Zealand)	475	12.70	9.90	75.25	7.38	101.45

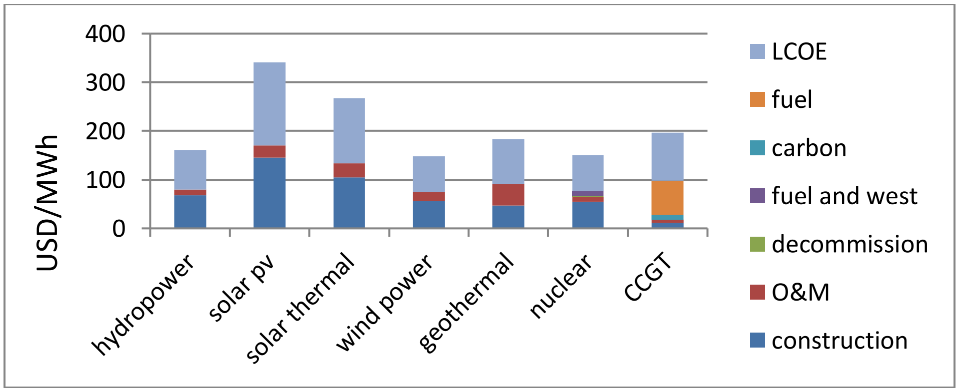


Figure 5. Levelised cost of electricity at 7% discount rate

IV. CONCLUSION

The importance of energy in economic development has been recognized almost universally; the historical data attest to a strong relationship between the availability of energy and economic activity. Ethiopia has plenty renewable resources for the purposes of renewable energy. Among on the selection of the most appropriate renewable energy investment for the country, this paper shows to make a decision for selecting the best renewable energy for future energy plan of the country depending on levelized cost of energy (LCOE). To facilitate the utility of this information, data of costs of energy presented by international energy agency for different countries has been used. Which are direct analogies with financial metrics commonly used to characterize electricity production technologies: overnight capital cost, operating costs and LCOE. Based on that, the results of the LCOE methodology suggest the wind energy as the best alternative, which is found to have the lowest energy costs. The ranking of energy alternatives is determined as Wind – Nuclear – Hydropower - Geothermal - Solar thermal.

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