



Pumped Hydro- Energy Storage System in Ethiopia: Challenges and Opportunities

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ABSTRACT

The shares of RE sources are rising because of global warming concerns and the depletion of fossil fuels. However, due to its intermittent nature sustainable power supply depends on the proper energy mix and energy storage. By 2025, Ethiopia has planned to export 24 TWh of energy. Accordingly, its power generation is incorporating different RE sources dominated by hydropower. This paper has reviewed the global up-to-date status of PHEs and Ethiopia's current energy situation and potential PHEs. The objective of this paper is to show Ethiopia's potential for PHEs and serve as a "Green Battery" for the East Africa Power Pool (EAPP). The review shows that PHEs can easily replace backup diesel generators used as a backup during a blackout. Moreover, it showed the Policy barrier for energy storage in the Ethiopian National Energy Policy proclaimed in 1994 and its 2012 updated policy. Thus, Ethiopia's energy policies need to consider PHEs in its energy storage strategy while expanding its generation.

Keywords: Renewable energy mix, Pumped Hydro Energy Storage, Ethiopia's energy resource, Renewable energy resources.

1. INTRODUCTION

1.1 Background

Ethiopia lies between latitude 3^o-15^o North, and longitude 33^o-48^o East in the horn of Africa. The country occupies a land of approximately 1.1 million km² with a population of 107 million. It is the second most populous country in Africa, after Nigeria (World Population, Data Sheet, 2018) (World Bank, 2018a). Ethiopia's economy is mostly dependent on agriculture with 84% of its population lives in rural areas directly or indirectly employed in agriculture and related activities. The landscape is mostly mountains elevated between 3000m and 4000m in the eastern part and low land surface between 1200m and 1000m towards the west. Such type of topography is well suited for hydropower and pumped-storage hydropower facilities (World Population, Data Sheet, 2018)(World Bank, 2018b).

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Ethiopia's electricity generation is dominated by hydropower. Figure 1 shows the current electricity generation capacity of Ethiopia, 4,284 MW, which consists of 96.6% renewable energy sources (Seleshi,2017).

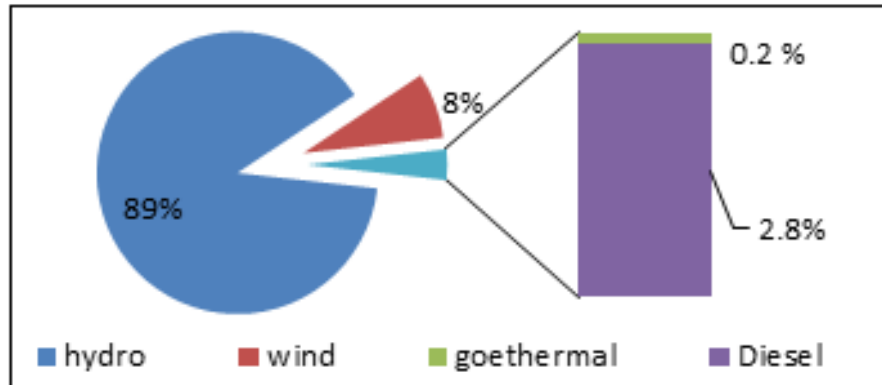


Figure 1. Electricity Generation capacity in percentage from different sources (Seleshi. 2017).

According to World Bank report the country has 4.5 GW installed capacity and a relatively advanced infrastructure network with nearly 80% of the population lives within the proximity of medium-voltage transmission lines (World Bank, 2018a). the country's access to electricity is 45 % in 2018 (United Nations Environment Programme, 2020) and the per capita electricity consumption is 83 kWh/year in 2020 (Renewable Energy Global, 2017). On the other hand, about 92 million people rely on firewood, charcoal, or dung for cooking purposes (Renewable, Energy Global, 2017). The total primary energy consumption in Ethiopia in 2016 is about 0.268 Quadrillion BTU (British Thermal Unit), which is equivalent to 78 TWh (Tucho et al., 2014). About 91% of this amount is predominantly supplied by biomass energy resources and their derivatives, while imported petroleum and electricity accounted for about 7% and 2%, respectively. Electricity is mainly used in urban areas by residential households as well as for commercial and industrial purposes (Tucho et al., 2014). Though majority of the rural households live within the proximity of medium-voltage transmission lines, they are not connected to the grid and benefited from the electricity supply system (World Bank, 2018a).

Energy plays a key role in the development and the economic growth of any country. According to the United Nations Economic Commission for Africa (UNECA), Energy is the first sector to be selected for Governance and Public Administration Division (GPAD's) focus. This is due to its central role in sustainable development and poverty reduction efforts (United,

Nations Economic Commission,2011). Ethiopia is following a green economy strategy and its economy is categorized as one of the fastest economies growing in the world (Seid,2016).

The study by Atems and Hotaling (2018) shows that electricity generation from renewable sources has a positive relationship with economic growth. Accordingly, analyzed the coefficient on renewable electricity generation of Ethiopia by using a two-step System Generalized Methods of Moments (GMM) and found it positive at 0.03. Figure 2 shows renewable capacity growth from 2007 to 2016 of Ethiopia, Africa, and the world respectively.

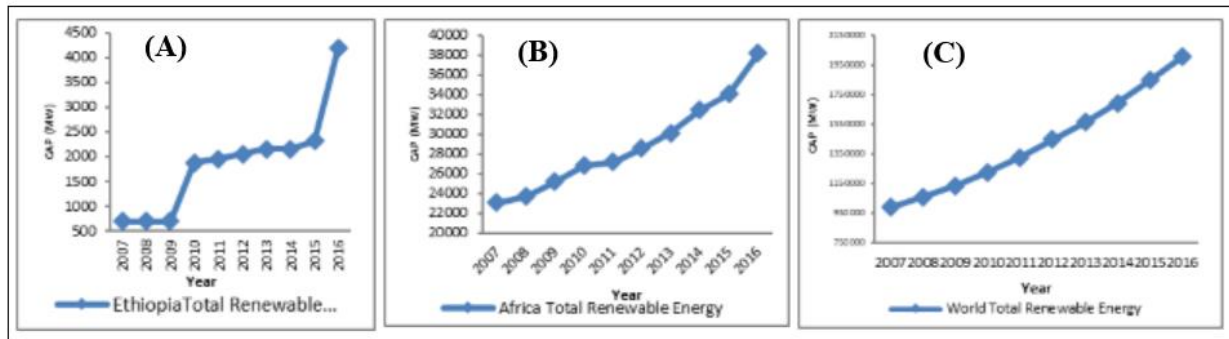


Figure 2. Renewable Capacity growth from 2007 to 2016 A) Ethiopia, B) Africa, and C) World. (Renewable and Agency 2017).

1.2. Renewable Energy Resources

Ethiopia is blessed with diverse types of energy resources, especially renewable energy sources such as hydropower, wind energy, solar energy, and geothermal energy as well as biomass resources. The water resource is one of the abundant energy resources in the country and the exploitable reserve of hydropower is estimated at 45 GW, which is 20% of total Africa’s technically feasible hydropower potential (Trade and Forum,2015). The government of Ethiopia, according to the Growth and Transformation II strategy, has planned to generate 11 GW from hydropower between 2016 and 2020. To achieve this target, the government is constructing the Grand Ethiopian Renaissance Dam (GERD). When completed, the GERD would have a total installed power of 6,000 MW from 16 Francis turbines, each having a generating capacity of 375 MW and would be the largest dam in Africa (Energy and Special,2019). Figure 3 shows the model and construction status of GERD.

Wind is another good energy resource available in Ethiopia with the potentially exploitable of 1,350 GW. By 2018 the total cumulative installed capacity of wind power in the

country was 324 MW and there is a plan to gradually increase capacity to about 2,400 MW by mid-2020. This would represent about 30% of the total power generation capacity, which is an estimated 17,000 MW in 2020 (Marena,2019).

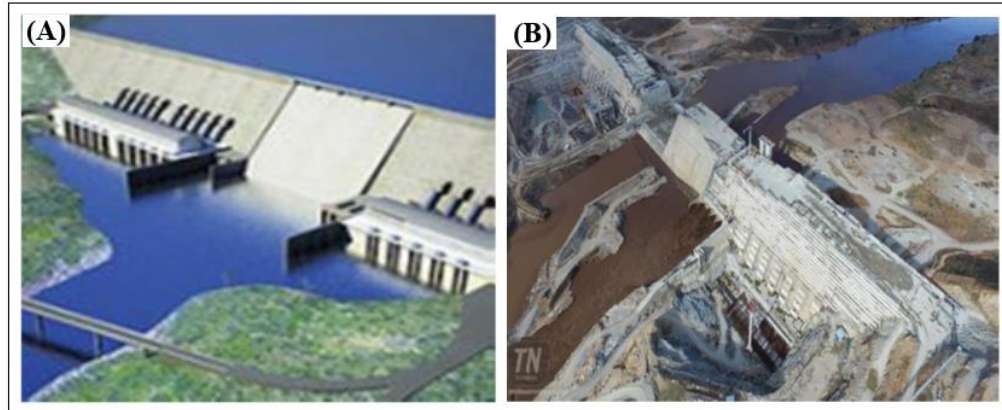


Figure 3. Grand Ethiopian Renaissance Dam, (A) model and (B) construction status (Ministry of Water Irrigation and Electricity 2017).

Ethiopia locates in the solar belt of the equator and receives average solar irradiation of 5.2 kWh/m²/ day. Despite this huge resource, less attention has been paid to large-scale solar energy development in the country until recently. However, the country includes solar to its generation plan and it is executing a 3,350 MW development between 2017 and 2025 (Marena, 2019). In addition, there is a goal to install about 5 MW in the off-grid. This will replace kerosene based lighting and off-grid electrical needs of villages to water pump, power health care, school lighting and power service centers.

Ethiopia's geothermal is found mostly along the Rift Valley region with exploitable potential of about 7 GW. However, only one geothermal power plant with installed capacity of 7.3 MW is operating in the country so far. Recently, a 1000 MW capacity, at Corbett 250 km south of Addis Ababa, is signed with Icelandic- Reykjavik Geothermal Company as the first independent power producer (Trade and Forum, 2015). In addition, the country has known reserves of coal (260 million tons), natural gas (4.7 TCF), and Bioenergy (96 M tons yield/y). However, it still relies heavily on bioenergy resources to meet its energy demands (URA and Gap Analysis on Sustainable Energy, 2013).

Even though the share of wind and solar would be about 11% in the 2020 energy mix of Ethiopia, its transmission and distribution systems lack adaptiveness and flexibility. Besides,

there is no grid-scale energy storage facility incorporated in this plan to stabilize the grid system to accommodate wind and solar resources into the energy mix. Experience of some countries, like China, had shown about one-fifth excess power of the installed wind power output in the system was curtailed. This was considered as loss of investment and revenue and this loss could be significant if the curtailment is during high wind speed period. Some of this curtailment is due to the lack of pumped-hydro energy storage capacity (PHES) (International Hydropower Association,2017), or any other grid-supported energy storage system.

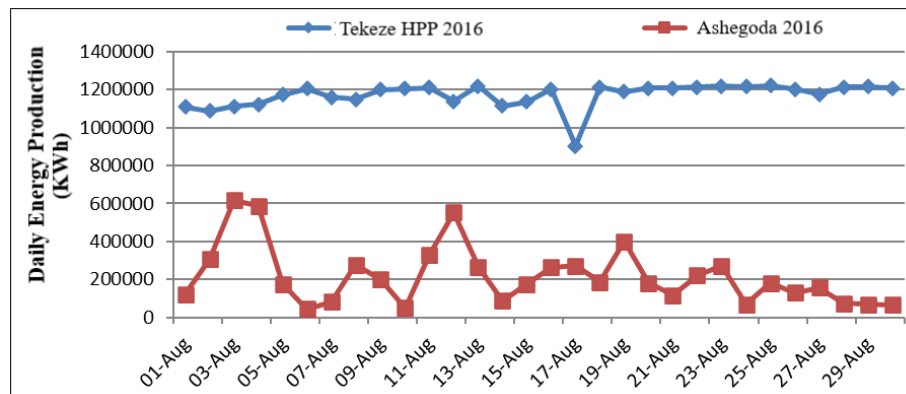


Figure 4. Daily energy production of Ashegoda wind farm and Tekeze hydropower plant. .

Figure 4 shows the daily energy production Ashegoda wind farm and Tekeze hydropower plant in August 2016. This implies large scale storage is a need to have stabilized power on the grid system. Thus, using detailed modeling of wind and solar power system to evaluate wind integration issues found that transmission and energy storage can both reduce wind curtailment (Jorgenson, Denholm, and Mai,2018).

1.3 The Need for Energy Storage

According to the International Energy Agency (IEA) around 80 GW additional energy storage capacity is needed worldwide by 2030 to meet the Sustainable Development Scenario (SDS) (McLarnon and Cairns,1989).

In the context of Ethiopia, the purpose of this paper is to review the situation of the electric power sector with its abundant but untapped resources and opportunities of PHES. In addition, it identified the barriers that hinder the implementation of PHES from the experience of other countries.

2. CHALLENGES OF CURRENT ENERGY SITUATIONS IN ETHIOPIA

2.1. Implications of Unreliable and Unstable Supply of Electricity

Energy is the vivid string that associates economic development, expanded social value, and a domain that enables the world to flourish. Economic growth is not imaginable without energy, and continuous advancement is not feasible without a sustainable energy supply. For a country like Ethiopia, with the expanding and larger share of power generation from wind and solar faces challenges of sustainable availability of power. This energy mix of the country is associated by continuous blackouts and brownouts (Load shedding) (Brew-hammond, 2010), which causes businesses to lose about 20% of turnover (United, Nations Economic Commission, 2011).

Ethiopia’s blackouts are affecting industrial productivity adversely, from 2011 to 2015 alone, and caused the firm’s operating cost to increase by 15% due to expansion of diesel backups (Barrie and Mathews,2010). The challenge to fulfill the optimum power demand and supply is a linear algorithm. Besides, unless consumed, electricity cannot stay on the grid. Figure 5 shows Ethiopia's active load for 24-hourelectricity consumption of May 1 from 2013 to 2016 (Africa, Powering, 2014). As the pattern of the graphs shows the demand is generally low from midnight 24:00 to 06:00 in the morning. Due to combination of many reasons regarding consumption and production, the demand and supply of electricity change frequently and there is a need for a supply and grid system to respond to these changes on time to avoid unnecessary load shedding. The unplanned load shedding could be significant in situations where the generation of electricity is dominated by intermittent renewables and if the grid system is not designed to handle this like the case in Ethiopia. Figure 5 shows that there is a gradual increase in peak load on May 1 from around 1200 MW in 2013 to about 1600 MW in 2016 in the country.

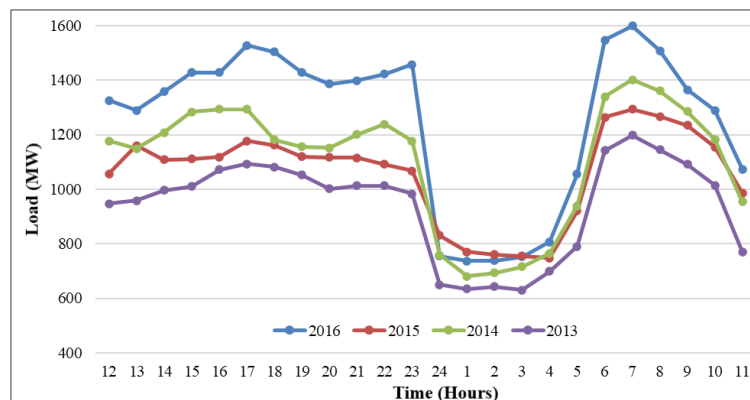


Figure 5. Active load on May 1st between 2013 and 2016 in Ethiopia electric grid (Dry season).

The graph resembles the duck curve during the day, resulting in a high peak load in mid to late evening. The difference between the Duck Curve and a regular load chart is that the duck curve shows two high points of demand and one very low point of demand, with the ramp-up in between being extremely sharp. Since the Ethiopia grid, power generation has 8 % from wind and increasing in the coming years; the duck curve will appear more often and can get worse.

2.2. Health Issues

In Africa about 600,000 premature deaths were attributed from household air pollution coming from the burning of solid fuels for cooking, while household diesel generators increase the risk of carbon monoxide poisoning and fires (Avila et al.,2017). In Ethiopia, most of the households still depend on solid biomass fuels for cooking. According to the WHO 2016 report, the ambient and household air pollution attributable death rate per 100,000 people is 82, 40, and 24 in Ethiopia, Kenya, and the USA respectively (Mondal et al. 2017). In this view, the negative health impacts from lack of modern energy in many households are severe in Ethiopia compared to the two countries.

2.3. Environmental Issues

In Ethiopia, due to the dependence on traditional biomass fuels, fuelwood consumption is rising by 65% annually (Ethiopia's, Climate-Resilient Green Economy,2011). This leads to forest degradation of more than 22 million tons of woody biomass in the country over the last two decades. As a result of this high dependence on forest resources, emissions of CO₂ increased from 26 Metric tons of carbon dioxide equivalent (MtCO_{2e}) in 2010 to 44 MtCO_{2e} in 2030(Ethiopia's, Climate-Resilient Green Economy,2011). Although comparatively, this is a small amount of emission contribution as greenhouse gases, recognizing the country's most vulnerable to climate change impacts such as droughts and reduced agricultural yields imposes a concern. However, PHES essentially demands to build of minimum one reservoir along across a river, which commonly influences negatively to the local ecosystem (Ampim and Maharjan, 2017). Besides, the conversion of an existing reservoir into a PHES system has a minor environmental and social impact compared with the high environmental and social impact of a new hydropower plant (Roberto et al., 2012).

3. PUMPED HYDRO STORAGE PLANTS

PHES generates power from stored water as a form of potential in the upper reservoir previously pumped from a lower reservoir. The basic principle of PHES is to store water in the form of potential energy in the high-level reservoir (1) (Fig 6) when there is an availability of excess energy generated from any of the renewable sources, typically during off-peak periods, used to pump water from lower reservoir (2). This stored energy be used when there is peak energy demand. The water stored at higher elevation will be released to flow back kicking the turbine and generating electricity (3), and the water be dispatched to the lower reservoir like conventional hydropower. Two basic parameters required as vital resources are the head or elevation and amount of water in the reservoirs.

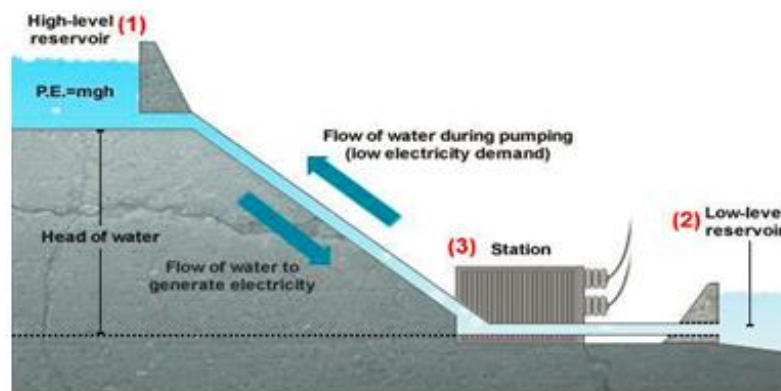


Figure 6. Schematic of a Pumped Hydroelectric Energy Storage Facility.

3.1. Global Pumped Hydro Energy Storage Status

Pumped hydro storage capacity installed globally is about 153 GW, of which about 51 GW is installed in Europe, 28 GW in China, 27 GW in Japan, 22 GW in the United States, and the remaining in the other parts of the world at the end of 2017 (International Hydropower Association, 2017). Figure 7 presents the regional distribution of PHES capacity (GW) at the end of 2017. China is striving to meet a target of 70 GW PHES capacity by 2020. South Africa is also constructing a new project of PHES by the national utility start generation with two units in early 2016 which will have a capacity of 1,332 MW (International Hydropower Association, 2017). Globally in 2015 and 2017 alone, an estimated new pumped storage of 2.5 GW and 3.2 GW capacity were added respectively into operation (IHA, 2017). According to Global Energy

Transformation, Pumped hydro will be more than doubles in the period 2015 to 2050 from 155 GW to 325 GW globally (IRENA, 2018).

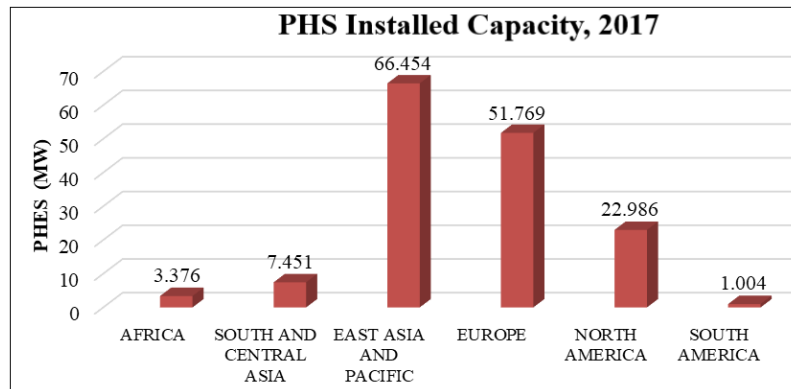


Figure 7. Pumped hydro storage capacity (MW) in operation in 2017 (IHA, 2017).

4. OPPORTUNITIES FOR PHES IN ETHIOPIA

Ethiopia has the opportunity to develop a large-scale pumped-hydro energy storage system and the largest PHES project in the world at the Danakil Depression. This is on the northern part of the Afar and can generate electricity of nearly 6 TWh. According to the assumption made by (Solomon, 2014) Permitting an extensive 10-meter swing top to bottom between completely charged and completely released states, as it is distinctive dedicated pumped storage reservoirs today. The other assumption is an average depth below sea level of the Danakil Sea of 50 meters, and an average surface area of the lower reservoir that is half the total area of the depression. Hence, if one meter per day is allowed a maximum swing in the level of the Danakil Sea, corresponding to the typical swing of natural tides, this would imply a daily cycle round-trip capacity of about 600 GW. For 12 hours charging, 12 hours generating, this would mean 46 GW maximum output, 57 GW maximum input, which would be by far the largest pumped storage project in the world (Solomon, 2014). Another opportunity is the low resource risk in Ethiopia than numerous nations in the region. This will ease investment in PHES. Ethiopia has turned into an eager accomplice, offering liberal motivations and supporting the investment with the fast development of pertinent infrastructure. Since 2017, the government has provided an opportunity to invest in the energy market to worldwide investors (Gordon, 2018).

4.1. Existing Infrastructure

PHES facilities require a relatively small reservoir as related to the conventional hydropower facilities. This is because the required working time of PHES is on average 4 to 20 hours (Antal, 2014). Hence appropriate PHES spots can be identified at some of the seventeen (17) existing and under construction hydropower plants in Ethiopia. And this can be done without affecting the ecosystem and dwellers. In addition, Ethiopia could be a potential for electricity storage, “Green Battery” of East Africa, with its large potential for electricity storage from hydropower reservoirs. The existing hydropower and the potential of hydropower, PHES can be applied, as a breakthrough for synergies with other water uses, such as freshwater demand from desalination and irrigation (Hülsmann et al., 2007). Besides, it is remarkably less difficult to change the existing conventional hydro reservoir to PHES than constructing a new PHES facility. After analyzing the economic feasibility of an existing hydropower plant, it is possible to transform it into a PHES site that can store energy for weeks and even months (Niall et al., 2012).

4.2. Wind and Solar power plants

In the past few years development of new power generation from renewable energy sources, especially solar and wind was growing in Ethiopia. This is a due combination of more factors, such as various national incentives and support schemes, climate change, and international commitment to reduce consumption of fossil fuel-based energy resources, as well as energy security and reducing dependence on imported energy resources by net energy importer countries. Ethiopia’s wind farms cumulative installed capacity is projected to increase to 5,200 MW by mid-2020. This new development creates a good opportunity for PHES investment (Council of Representatives, 2013).

4.3. The Market in the Neighboring Countries

The establishment of the East Africa Power Pool (EAPP) in 2005 by seven nations, Burundi, DRC, Egypt, Ethiopia, Kenya, Rwanda, and Sudan, was a new era for the power-sharing zone. EAPP has discharged all-inclusive strategies and regional power framework planning and anticipating being completely operational within some time. The EAPP has released master plans and regional power system studies and is projected to be fully operational within several years (Avila et al., 2017). One advantage of the power pool is to accelerate the economic growth of the region by creating a regional network of power-sharing and available resources (Avila et al., 2017). Ethiopia is currently selling power up to 250 MW and 90 MW to Sudan and Djibouti

respectively and planned to sell up to 2,000 MW power to Kenya by the end of 2019 (Ministry of Water Irrigation and Electricity, 2017). To accomplish these targets, which could bring extra revenue to Ethiopia, reliable energy generation system complimented with a large-scale energy storage system would be essential.

4.4. GHG Emission Reduction

For the carbon compelled world, a novel chance to make use of and derive benefits from large intermittent wind and solar resources can be using large storages of PHES to fulfill the electricity demand (Barnes and Levine, 2011). According to the World Bank Group State and Trends of Carbon Pricing 2018, there is an increment in most initiatives in carbon prices in 2018 relative to price levels in 2017. And as of 2018, 45 national and 25 subnational jurisdictions have a carbon pricing structure in place (World Bank Group, 2018). And the carbon prices vary significantly, from less than the US \$1/t Carbon dioxide equivalent (CO₂e) to a maximum of US \$ 139/t CO₂e (Pricing, State and , 2018). In Ethiopia eleven (11) diesel plants with a total capacity of 112 MW are available (Tucho et al., 2014). Taking the energy produced by diesel plants in 2015/16 alone, which is 1.02 TWh, would have been reduced a GHGe 743.62 tons of CO₂. Taking into account that Oil-fired power plants typically emit about 731 grams of CO₂ for each kWh produced (WNA, 2011). Hence, during blackout standby diesel generators, which are in place, can be replaced with PHES.

5. CHALLENGES OF PHES

Although energy storage is one of the important potential areas that could considerably affect global future energy needs, it is one of the challenging research areas (Chu and Majumdar, 2012). The challenges of building new PHES vary from the environmental legislation (Environmental Impact Assessments) to the duration of permitting procedures. According to the United States' National Hydropower Association (NHA, 2018), PHES development has some degree of complexity and risk significant regulatory, market and financing hurdles that other energy storage technologies typically do not encounter (NHA, National Hydropower Association, 2018). However, when it comes to the developing countries, the development of PHES has additional barriers, such as lack concrete policy, investment cost and retail price of electricity as well as political uncertainty, which could repel potential investors.

5.1. Fixed Electricity Tariff

According to Deane et al. (2010) for a PHES to be economically viable, the price for pumping (or charging) should be at least 25–30% less than the selling price. However, in Ethiopia, where electricity tariff is fixed, irrespective of Time of Use, there is generally no differentiated rate during low or peak demand periods. Hence, the cost of charging the PHES and generating electricity is the same and considering inefficiency in the pumping and generating systems, this would result in economic or financial losses to the operator of PHES in Ethiopia. However, sustainable availability of power is a great concern and this could be solved by integrating large energy storage to the power sector. In this view, PHES becomes a feasible large scale storage technique that is fit to the economic development of the country and will address the tariff based economic feasibility ones Ethiopia become a key player in the east Africa Power Pool.

5.2. Financial Constraints

The huge initial financial investment required to develop power plants from renewable energy sources is the major barrier of energy development in Ethiopia like other developing countries. This is due to the broadly disseminated nature of allocation these resources need more innovation and intellectual property turn out to be more imperative in relative terms than the convection fossil fuel resources. A secondly related constraint would be potential rivalry regarding sustainable power source foundation with the existing well-established infrastructures from fossil fuel. In Africa, acquiring the source of global financing is the principal real hindrance for some renewable energy projects. Reaching a financial close can reach over five years longer for African projects than for their counterparts in more stable investment environments (Gordon, 2018).

5.3. Policy Barrier

In Ethiopia, the main energy policy is the National Energy Policy proclaimed in 1994. This energy policy and the updated national energy policy of 2012 give more emphasis to the expansion of conventional hydropower and diverse energy mix. Nonetheless, energy storage is not stated in both documents (MWE, 2012). However, energy policies on storage, steady administrative structures, and expanded approach exchange are important. Because the maximum challenge for energy policymakers be to move far from an isolated, supply-driven point of view towards one that empowers frameworks integration (Energy and Transformations,

2017). Different countries are introducing in their policies to encourage storage. For instance, in China, the government includes a two-part feed-in tariff, which is specific to pumped-storage plants. This structure acknowledges the technology's important role in providing reserve capacity and the value of PHES subordinate energy services (International Hydropower Association, 2017).

6. CONCLUDING REMARKS

To satisfy the electricity demands in a stable, reliable and balanced manner, development and implementation of energy storage systems in the country's future energy mix would be crucial. Therefore, it is imperative to analyze the technical and economic effects of the flexible, renewable power sources on Ethiopia's energy system. With recent innovative and cutting-edge technology development of adjustable speed pump/turbine PHES, which improved their operating efficiency, implementation of PHES would greatly improve electricity supply in the country.

With all the benefits of pumped-hydro power energy storage systems especially to improve quality of power supply, no potential assessment of PHES has made so far to the authors' knowledge in Ethiopia. Unless planned wisely, the desire of the country to have renewable energy-based power system in the future might not be achieved and would likely be replaced with backups mostly diesel generators, as an alternative the source of power by industrial and commercial sectors. This can slow down the economic growth due to hard currency in importing the crude oil and affecting the green economy growth with the CO₂ and GHGs.

Besides diesel plants operated in 2015/16 alone produced 1.02 TWh which is equivalent of GHGe 743.62 tons of CO₂ would have been avoided by replacing it with PHES. The other benefit of storing excess energy in the form of electricity will transform the transportation sector by using synthetic fuel and fuel storages for electric vehicles. This would have multi-benefits, such as save foreign currency, increase energy security and reduce emissions. The penetration of wind and solar energy systems are major parts of Ethiopia's Climate-Resilient Green Economy (CRGE) strategy.

Therefore, the responsible government agencies and departments should consider the potential of PHES in Ethiopia sustainable energy plan. Besides, there must be the provision of incentives as a regulatory framework to support electricity storage systems with mechanisms like time-of-supply variable as feed-in tariffs.

7. ACKNOWLEDGMENTS

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