Study of the Potential of Sea-Water Pumped Storage for Power Generation: Zway Islands in Ethiopia

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***Abstract*—Questions for the access of energy are continued in different part of sub-saran Africa. One possible solution to these challenges is to hybridize renewables with conventional power systems and to include energy storage units. In this study, the evaluation of the sea-water storage potential of Zway Islands is presented as the first step before designing low carbon renewable-based energy supply system for communities on the Zway islands in Ethiopia. To investigate the pumped-hydro storage (PHS) potential, a GIS-based analysis is done using a 3D computer graphics representation know as digital elevation model (DEM) by considering the lake as the lower reservoir. The elevation is determined by using an optical remote sensing technology, DEM Light Detection, and Ranging, DEM(LiDAR) 12.5-m instrument, which is one of the highest resolutions. Others included in the selection matrices are the topography, area, head, and slope. As a result, twelve upper reservoirs are identified within the head range of 50-250, 50-200, and 50-100m. In the process, island Tedecha is found to be of the highest potential candidate followed by Tulu Guddo and Funduro. The investigation proved that a small-scale pumped hydro-storage system can be developed with a minimum storage capacity of (503kw) x (12h).**

***Index Terms*—DEM, Ethiopia, GIS, Pumped hydro-storage**

I. INTRODUCTION

a) Overview of Ethiopian Energy situation

Access to clean and affordable energy plays critical role for survival of African as a continent. In sub-saran Africa around 600 million people and in Ethiopia, based on estimated value for the first half of 2020 around 53 million lack access to electricity, typically in rural areas [1]. It was reported [2, 3] even at the end of the year 2025 for Ethiopian national electrification program, only 65% of the population will have access to electricity. The remaining 35% of the total population will continue to live without access. Ethiopia faces energy challenges on different fronts (i) meeting the energy need of people who lack access to modern energy; (ii) meeting the energy requirement of a growing economy and the delivery of power for neighboring countries. To address these challenges as well as to meet the Sustainable Development Goals for Energy (SDG 7), the country's Climate Resilient Green Economy Strategy (CRGE), which aims to protect the country from the adverse effects of climate change and build a green economy, is vital instrument for the development of sustainable energy supply. The four pillars of Strategy include the generation of energy from renewable sources for domestic and regional markets and the introduction of modern and energy efficient technologies. In transforming Ethiopian's industrial sector as the main driver, the government has an ambitious plan of boosting the share of the renewable energy in the national energy balance to a significant portion by 2030, i.e., 22GW from hydro, 7GW from wind & 1GW from geothermal. This is in line with the ambition of becoming a middle-income country by 2025 [4, 5]. Accordingly, the development of renewable energy in the country is increasing from time to time as shown in Fig 1

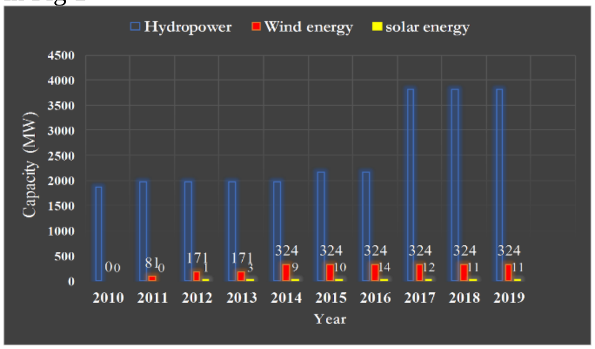

Fig 1. Renewable energy capacity installed [6]

For satisfying the ever-increasing need for clean energy for its population, especially for the off- grid community, using a hybrid energy generation system consisting of renewable energy resources is mandatory and appropriate. According to the international renewable energy agency (IRENA) report, over 80% of solar photovoltaic (PV) and 75% of wind projects to be commissioned would produce electricity cheaper than any oil, coal, or natural gas option [7]. However, the intermittent nature of the resources needs to be thought of, as it may cause system instability problems. Hence, the hybridization of different renewable energy sources coupled with an energy storage system can significantly improve the system's instability and reliability [8]. This particular study is aimed at investigating the potential of the pumped hydro-storage system to be used as a backup for stand-alone hybrid solar-wind based electricity supply systems for the community estimated to be over 5000 living on the Islands without electricity.

b) Pumped storage system

Pumped storage system stores energy in a form of gravitational potential energy of water. It may consist of a power generator (Solar PV, wind, hydropower, etc.), an energy storage system both in the upper and lower reservoirs, pump (P), turbine (T) / motor(M) / generator (G), and end-user and control as shown in Fig2 [9].

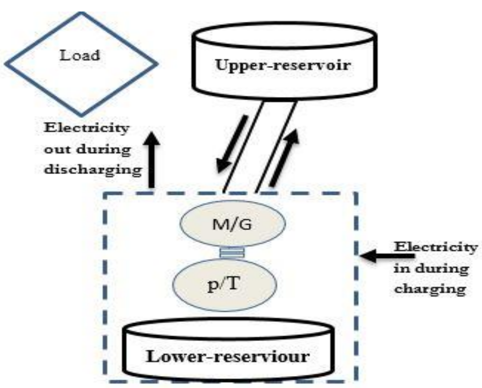

Fig2. Pumped storage system

c) Why the need for a pumped storage Energy system in Ethiopia?

- Pumped storage coupled with renewables (Wind and solar PV), can significantly promote off-grid electricity generation
- Not only there are other islands in lakes where significant number of people live on, but also huge population around riverbanks where power can be developed by using pumped hydro storage systems.
- It is also to be noted that more than 90% of electricity production is dependent on conventional hydropower venerable to seasonal variation and sometimes unable to meet peak demands. This must have a solution
- Distributed Generation can be used to inject power into the distribution network of the power system to improve power quality problems and waterpower storage can be a solution.
- The grid instability problem as a result of the power expansion plan through increasing the share of the weather- dependent renewable energy sources can also be considered and stored water energy can sometimes be utilized.

The subject of the Pumped-storage system in the Power sector in Ethiopia has been under-researched, and related knowledge is limited. Empirical evidences show that very few studies on pumped storage hydro have been documented in Ethiopia [10, 11]. Those studies aimed at integrating the convectional hydropower with a pumped storage system for Tana Beles and Koka hydropower. None of the studies conducted before investigated the closed-loop pumped storage option. Again, a number of studies in the country conducted on electrifying the off-grid community through a stand-alone hybrid system[12-14] did not consider PHS as an integral part of the hybrid Energy generation they designed. According to [10] future studies could offer insight into the technical design of pumped storage systems that may be done using software. Discovering and analyzing potential areas for the pumped-hydro storage system and feasibility study of solar/wind hybrid power generation need to be done with the help of precision instruments and software. This study bridges such gap by applying clothed loop pumped storage hydro using DEM(LiDAR) at 12.5m resolution for evaluating stand-alone solar-wind hybrid energy generation system. The study considers natural lakes as greenfield projects for a lower reservoir. The utilization of a hybrid system (Wind, Solar and Pumped Storage) for power production for the islands or other interconnected regions, appears to be the best solution to overcome the problems of inaccess to electricity. For small islands with low installed capacity and other applications, the pumped storage system seems to be the most promising way of exploiting the renewable energy resource potential at a high degree of penetration [15].

II. THE STUDY AREA

Remote Zway islands named Tulugudo, Funduro & Tedecha (7° 51'N to 8° 7'N and 38° 43'E to 38° 57'E) are the case studies of this paper (Fig3). These islands have no access to electricity. Due to the economic challenges of the country and the landscape the grid does not reach. Over 5000 people live on the islands. Kerosene for lighting, diesel for Irrigation & water pumping, firewood for cooking & dry cells for radio are used by the inhabitants.

III. METHODS

To investigate the pumped storage potential of the Islands, a geographic information system (GIS) based topographic analysis is performed using digital elevation models (DEM). The elevation information of the study area is extracted with DEM (LiDAR) at 12.5-m spatial resolution. In visualizing potential sites for upper reservoirs Google Earth is used in 3-D mode and the overall potential determination is based on what is shown in Fig 4

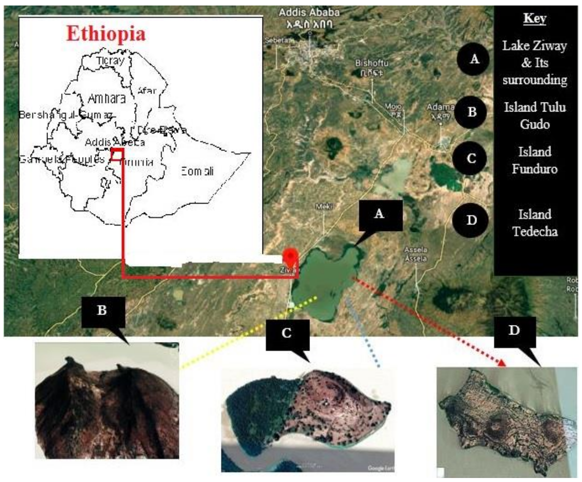

Fig3. Areal Map of the study area (Google Earth 2019)

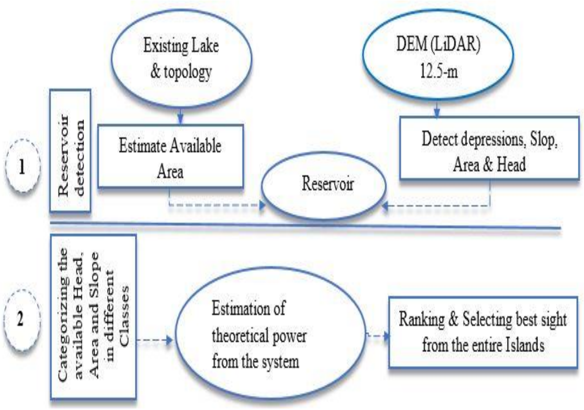

Fig 4. Methodological flowchart for evaluation of the pumped storage potential of the islands.

The theoretical power of the system from the flow chart can be calculated by applying eq. (1)

$$p_c = \rho * g * Q * h * \eta_T \quad (1)$$

Where: Pc=Power Capacity [W], h=head in[m], Q= flow rate in m^3/s, η_T=efficiency of the turbine

The maximum capacity of upper reservoir is given by eq. (2)

$$Eee_{max} = \frac{V\rho g h \eta_{pump}}{3.6 * 10^6} \quad (2)$$

Where: Eee_{max}, the maximum excess energy available to be stored from all the day cycles, in kWh; V is the water volume in m^3; η_{pump} is the pumping efficiency; factor $3.6*10^3$ is conversion factor from Joule to kwh. Algorithms with defined search and selection criteria or decision rules with minimum required preconditions for development of pumped storage system is established in Fig 5

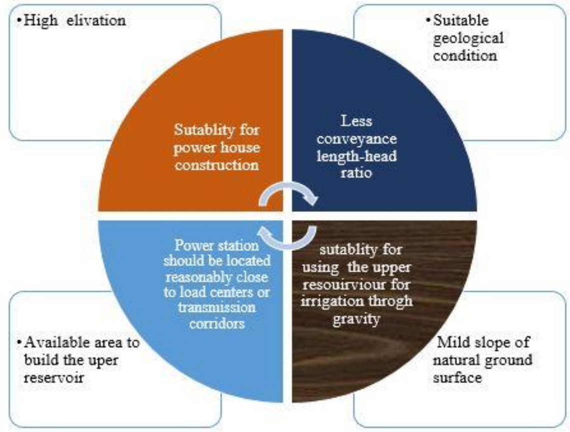

Fig 5. Decision rules for selection of pumped storage

IV. RESULT AND SISCUSSTION

As is mentioned in previous section, this section discusses a GIS-based suitability analysis for PHS site selection. It can be considered as a compliment to a conventional decision-making procedure to perform comprehensive site selection process.

(a) Head, area and slop determination

The available head for the three islands (Tulu Gudo, Tedecha, and Funduro) is presented as follows. The analysis is done using the digital elevation model Light Detection and Ranging DEM (LiDAR) with 12.5-m spatial resolution as presented in Fig 6

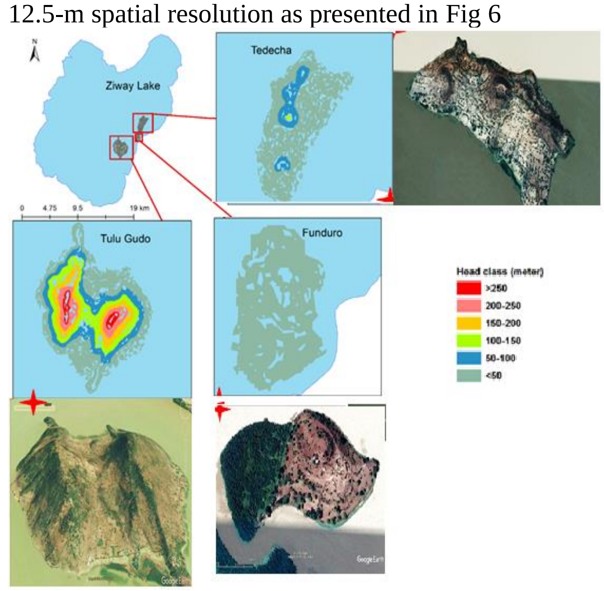

Fig 6.Available heads (DEM, Google Earth, 2019)

The elevation information of the islands presented in Fig 6 is filtered out based on the selection criteria metrics set before running the software, i.e., high elevation, relatively lower slope, enough area for upper reservoir and proximity to the community. The extracted head is in the range of 50-300m, 50-200m & 50-100m for Tulugudo, Tedecha, and Funduro respectively. The power generation capacity of the PSH depends on the available head (eq. 1). However, due to the searching criteria the slope of Island Tulugudo turned out to be of relatively high, that of Tedecha the highest and that of Funduro the lowest.

This study is in agreement with the study reported by Lu, B., et al. [16] and accordingly, the islands are one of the potential sites. A slop value of 0-10 degrees is chosen as an acceptable flatness of topography of potential transformation site. So, it is an advantage for PHS site selection when slope of natural ground surface is mild (e.g., slope < 10%) [17]. Areas that have a slope between 0 & 30 are filtered out using the reclassifying tool and then transformed into polygon areas. These polygon areas are now the potential reservoir sites and presented in Fig 7. Within a head range 100-150m the reservoir has a capacity of 24090m^3. With a 100m head and assuming 12-hours discharge & 90% generation efficiency, the flow rate of discharge is 0.569504m^3/s, the power generated is 503kw. This can be small-scale PHS with a minimum storage capacity of 503 kw*12h. Finally based on all decision rules set in the methodologey section the Pumped hydro storage potential of the islands is determined and presented in Fig 8.

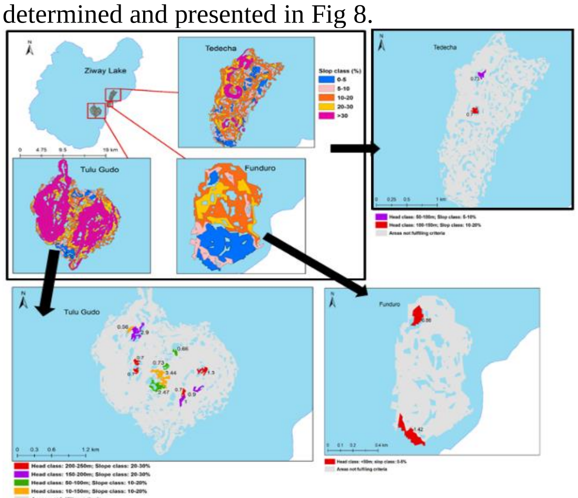

Fig 7.Slop class, area, and corresponding head according to (LiDAR, DEM,2019)

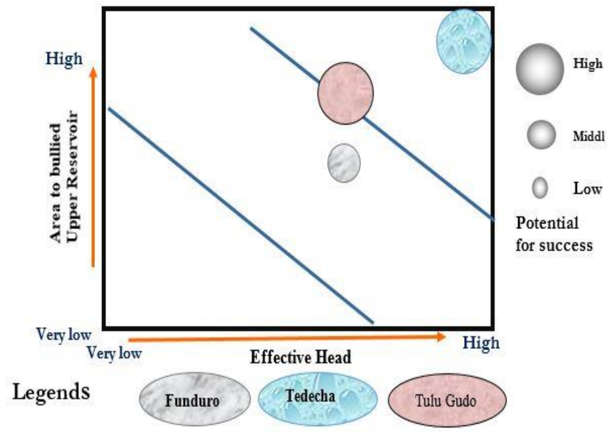

Fig 8.Pumped hydro -storage potential of the islands.

I. CONCLUSIONS

Sustainable economic growth and energy security are two of the most crucial concerns that entail Ethiopia to reduce its dependence on traditional and imported energy sources. This study attempts to analyze PSH potential of Zway islands namely Tulugudo, Funduro &Tedecha. Google Earth is used for the visualization of the topography in 3-D mode and the potential sites for upper reservoirs. The analysis of the elevation is performed using the digital elevation model Light Detection and Ranging DEM (LiDAR) at 12.5-m spatial resolution. High elevation, relatively lower slope, enough area for upper reservoir and proximity to the community are set as selection criteria matrices before running the software. Hence, twelve upper reservoirs are determined within the head rang of 50-250,50-200 & 50-100m. Island Tedecha is found to be the best candidate followed by Tulu Guddo & Funduro. The investigation proved that small-scale PHSS can be developed with a minimum storage capacity of 503kw*12h. The authors believe that the findings here can be taken as a role model for other similar situations across the country and elsewhere where access to electricity is low.

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