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The feasibility of renewable energy sources for pumping clean water in sub-Saharan Africa: A case study for Central Nigeria

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ABSTRACT

With less than 6 mm of rain from November through February every year, the central regions of Nigeria are in acute need of safe and consistent water supplies for drinking and other domestic or agricultural uses. Borehole supplies are capable of meeting a significant proportion of water needs, but ongoing fuel costs to power a generator and pump add a heavy burden to already disadvantaged communities. In this study, a techno-economic analysis is carried out in order to assess the feasibility of renewable energy sources and technologies to substitute for fossil-fuel powered pumping platforms. The results indicate that there is sufficient solar resource throughout these regions to facilitate relatively cost effective water pumping solutions, as well as a potentially effective wind resource depending on the exact location of the pumping station. Although systems based on these resources have high capital costs compared to petrol or diesel-based platforms, over a 20-year project life, the analysis indicates that ongoing fuel costs for a fossil-fuel-based system greatly outweigh the increased up-front costs of renewable alternatives. In conclusion, the results indicate that if the water demand at a particular site exceeds the capabilities of a hand pump, a renewable energy-powered pumping system is an attractive option, both economically and logistically in comparison to fossil-fuel-powered alternatives.

1. Introduction

1.1. Background

In the rural regions of central Nigeria, including the states of Plateau, Bauchi, and Kaduna, an agricultural subsistence economy predominates with a growing season defined by rainfall patterns. Precipitation peaks above 300 mm in August and then reduces to below 6 mm for November, December, January, and February combined [1]. In these winter months, agricultural production is greatly reduced and water for drinking, cooking, washing, and bathing becomes extremely scarce. In these regions, water is obtained predominantly from streams and open wells which often dry up during the winter months, and therefore water conservation is an imperative [2]. Furthermore, when surface water resources are available, they are often contaminated, and can cause water borne illnesses such as cholera. According to the World Health Organization (WHO), such diarrhoeal diseases, caused by unsafe water supply, sanitation and hygiene, account for approximately 119,700 deaths in Nigeria each year [3]. Additionally, streams and other surface water resources are often a considerable distance away from villages, and the terrain can be dangerous to traverse, especially while manually transporting a large volume of water. In such locations, women and children will make early morning journeys of up to 10 km to obtain water, with subsequent journeys being required again throughout the day, which interfere with education and other activities.

To confront these issues, community boreholes can provide a safe and convenient water supply. When the water demand from borehole supplies is greater than a hand pump can provide, an electric pump is commonly used. However grid electricity is rarely available and inconsistent when it is, so petrol or diesel generators are used. This burdens the already struggling communities with ongoing fuel and maintenance costs. In addition, fuel supplies can be intermittent. To overcome these issues, governments, NGOs and charities are exploring the potential of using renewable technologies to power water pumps at less of an ongoing financial burden.

1.2. Objectives

The purpose of this study is to determine the feasibility of using renewable energy to replace petrol as a source for pumping water by:

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- Identifying and quantifying the sources of renewable energy suitable for powering a borehole pumping system in the rural regions of the Plateau, Kaduna, and Bauchi states.
- Identifying or designing suitable systems to use those sources in Jos, Plateau State to pump water from a borehole with typical specifications and water demands for the region.
- Performing a techno-economic analysis of those systems comparing them to the traditional petrol generator/electric pump system, to determine which would be most suitable.

1.3. Precedents

In the developing world, hand pumps are the most common source for pumping water and when their capabilities are exceeded generators and/or grid electricity are then used [4]. Of the renewable resources, solar energy is the most commonly used source to pump water due to the abundant and consistent resource in these mostly subtropical regions [5]. This is especially true of Nigeria and other sub-Sahara African countries [6]. Wind energy has been used for centuries to pump water for drinking, irrigation and drainage, and today is used widely in African regions such as Egypt and Kenya as well as in Middle Eastern regions such as Jordan and Oman where the average wind speeds are often in a favourable range of 5–7 m/s [7–10]. Hydropower, biomass, and biofuels can also provide feasible sources of energy to pump water however their use is less prominent due to their inconsistent supplies in the developing world [4].

Several studies show that some renewables can be economically favourable compared to diesel generators for pumping water in the developing world. In Sudan, wind-mechanical systems were found to be less expensive than diesel systems, however wind-electric systems were not [11]. Similar results have been shown in Jordan and India, as well as the economic favourability of PV systems over diesel [12,13]. The potential of a renewable energy system is highly dependent on the available resource, which can vary greatly from region to region. One study in southern Nigeria evaluated PV in comparison with diesel for rural electrification and found that PV was not competitive [14]. However, the solar resource available in southern Nigeria is significantly lower than that in central regions.

2. Renewable energy resource assessment

To determine the feasibility of a renewably-powered pump, the available energy sources in central Nigeria must be quantified. This information was obtained and verified via both analysis of available data (such as from wind and solar atlases) and site visits to the town of Jos and nearby villages in Plateau State. The results are summarised below.

2.1. Manual pumping

Human power, specifically for hand pumping, is estimated to be 50–75 W at a comfortable level for a prolonged period of time. However, with each person filling only one or two buckets before moving on, a much higher level could be sustained throughout the day [4]. The limitations on hand pumping then fall mostly on the efficiency of the pump. The Afridev pump used widely around Africa achieves discharge rates of 0.8–1.35 m^3/h at depths of 15–45 m [15]. Therefore, for a 30 m borehole, which is typical of such projects, a discharge rate of approximately 1 m^3/h can be achieved. Hand pumps are often operated up to 12–16 h per day, but since they are not used continuously, an effective operating time of 6–8 h per day can be assumed [4]. In these situations water volumes of 6–8 m^3/day is achievable.

Hand pumps are also useful in villages with a widely distributed population, as is the case in Chokobo. A borehole and hand pump has been installed and although the population of the village is approximately 4000–5000, the hand pump is unused for most of the day. Because the village is spread out over such a wide area, most of the settlements utilised the often contaminated water from more closely situated streams and open wells. In cases like these, the installation of several boreholes throughout the village with hand pumps would be more effective than pumping large volumes of water from a single borehole.

2.2. Hydropower

Rivers, streams and other bodies of water can often provide an effective and inexpensive energy source for pumping clean water using ram pumps, turbines, or river-current pumps [4]. In the central regions of Nigeria, these bodies of water are highly variable if they exist at all, and are not always in close enough proximity to the pumping site. For these reasons, hydropower is not considered in this study.

2.3. Wind energy

The wind speeds for the cities of Jos, Bauchi and Kaduna are shown in Table 1 at a height of 15 m and assuming a flat terrain with a roughness length of 0.06 m, which is associated with the high grass and crops typical of these regions. As shown, the wind resources in these Nigerian locations are not as favourable as in the countries of Egypt and Kenya.

As a benchmark, effective electricity generation from wind energy requires an average wind speed greater than 5 m/s. However, for wind-mechanical pumps, lower wind speeds can be sufficient [18]. Even with an average wind speed as low as 2.5 m/s, wind-mechanical pumping can still be economically feasible [19]. For these reasons, only wind-mechanical systems are considered in this study.

Generally, an average annual wind speed greater than 3.5 m/s and an average wind speed in the least windy month of more than 2.5 m/s is required as a feasible resource for mechanical wind pumping [4]. This would rule out Kaduna and Bauchi as potential sites. However, Jos has an effective wind resource with which to pump water. In reality, wind characteristics are highly variable depending greatly on local climate and topography, and a detailed assessment of the exact site should be performed before embarking on any wind energy project.

The other caveat to using wind energy is that wind system supply chain in Nigeria is currently underdeveloped; during the research for this study, no companies in Nigeria were found that could actually supply or install a wind system. For this reason, the availability of a wind pumping system should be ensured before considering wind energy as an option. Alternatively, there may be a business opportunity in bringing wind pumping technology to Nigeria.

One of the benefits of wind-mechanical systems is their simplicity, and Schumacher states that for a solution to be appropriate and sustainable, it should employ local skills and material resources [20]. Wind pumps could easily be assembled and

Table 1
Wind Resource at a Height of 15 m [16,17].

Location	Average annual wind speed	Average wind speed in least windy month
Jos	4.2 m/s	3.7 m/s (October)
Kaduna	3.4 m/s	2.3 m/s (October)
Bauchi	2.7 m/s	2.3 m/s (August)