EXPLORATION AND MODELLING OF RENEWABLE ENERGY SOURCES AND MINI-GRID INSTALLATION OPPORTUNITIES IN ZIMBABWE

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ABSTRACT

There is a major power deficit in Zimbabwe that needs to be addressed by innovative means. This was mitigated by the fact that, after many years under international sanctions in the 70s, Zimbabwe experienced a sudden economic upsurge as the people and the commercial sector accessed the international markets. This happened between 1980 and 1990. The country, at one point, experienced the highest economic growth in the region (at 5.5%). There was, however, a delayed response in addressing the infrastructural development requirements of the energy sector to move in tandem with the desired economic growth consequently, the country has failed to meet its 2200Mw energy demand. The climatic conditions, and, the existence of many perennial water bodies point to a very lucrative hydro-power generation capacity. However, the capital demands to drive this vision, and, transmission grid that is not widely spread to the viable sites, renders these renewable energy resources inaccessible. A study, under the Rural Electrification Agency and the African Development Bank (ADB) availed these opportunities for public scrutiny. This paper considers the economic benefits of utilising these options as stand-alone mini grid plants, with options for solar energy and sustainable development strategies.

1. INTRODUCTION

Zimbabwe acquired its political independence in 1980. This brought with it high hopes and prospects of a lasting economic transition for the rural folks whose life was characterized by poverty, retarded progress and very limited exposure to the international community. This resulted in a sudden growth of the middle-income bracket of the population as the standards of living for most people shifted due to the various changes and education. This phenomenon placed pressure on the energy needs of an infant nation which sought to, (1) attract more FDI for job creation and exploitation of its mineral resources, (2) improve standards of living for most of its people and, (3) avail economic opportunities for the previously marginalised people. The economy of the country was also emerging from isolation due to sanctions that had caused the industrial, technological and economical driving forces to miss the competitive phase of the late 1970s [1]. These salient factors placed pressure on the energy sector to perform on overdrive. Investment and planning in the energy sector could not match the demand. The country experienced positive economic growth until in the 1990s [2].

1.1 Description of the socio-economic aspects of Zimbabwe

Zimbabwe is a landlocked Southern African Country which has a total land area of 391,000km^2. The Country shares its borders with Zambia to the northwest, Mozambique to the east, Botswana to the southwest and South Africa to the south. It has a population of approximately 16 million people. Zimbabwe achieved its highest levels of economic growth between 1980 and 1990 with an average GDP growth rate of 5.5 per cent - higher than the average for sub-Saharan Africa in the same period [2]. There was however, a marked economic decline between 2000 and 2008 due to political, social and economic issues and the loss of international support. The economic collapse was basically triggered by disturbances to the agricultural sector following the introduction of Zimbabwe's Fast Track Land Reform Programme in 2000. The programme saw the redistribution of commercial farms to the indigenous population, who relied mostly on rainfall-fed agricultural activities for subsistence [3]. Poverty levels grew during the period leading to an increased dependence on natural resources exploitation especially among the people living in rural areas which is approximately 70% of the population.

Electricity is the principal energy in the commercial sector of Zimbabwe. This drives the industrial hub of Zimbabwe which is mining, and engineering based. There is an increased focus towards agro-based economic activities as the government seek to turn-around the economy. Dependence on rainfall, especially in this era of global warming, where rainfall patterns are erratic, might scuttle these efforts [3]. The emphasis therefore would require, a focused investment into power generation and sustainable power availability to drive the targeted economic turnaround strategies. There are three sources of electrical energy in Zimbabwe. These are the hydro, thermal and imports. The energy policy of the country also seeks to increase reliance on renewable sources [4,5]. Table 1 shows the energy matrix of Zimbabwe. Most of the electricity is produced by the Kariba dam with a capacity to generate 750MW (40 per cent of national supply), and Hwange thermal power station. The national electricity demand is about 2.200 MW, only about 1200 MW is generated in Zimbabwe. The rest is outsourced from neighbouring countries [6].

Table 1. Power Generation and Supply.

Station	Energy (MW)
Hwange	506
Kariba	716
Harare	0
Munyati	16
Bulawayo	12
Total	1250

Low water volumes since 2007, compounded with old equipment, has also affected the production capacity of the Kariba hydro-power station. The thermal power stations are also constantly failing due to outdated technology [7].

Strategically, the Zimbabwe power supply situation should assume a position as given in figure 1. It is the purpose of this research to explore the available off-grid power generation options and assess their disruptive impact to the power challenges currently affecting Zimbabwe.

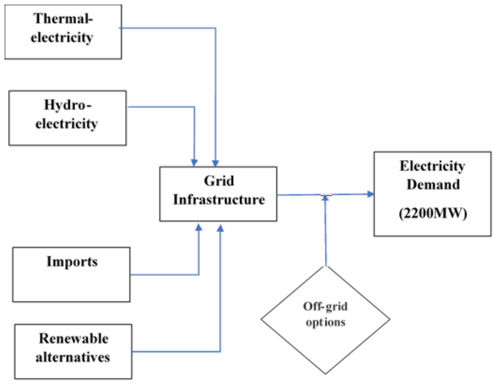


Fig. 1. The targeted disruptive effects of the Off-grid options.

1.2 The climate of Zimbabwe

The climatological evaluation of Zimbabwe positions it as a country endowed with on average, good rainfall patterns (at an estimated annual precipitation of above 600mm) and hours of sunlight as shown in figure 2 and 3 below [7].

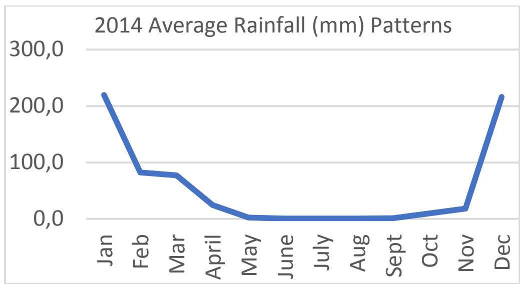


Figure 2. Zimbabwe typical rainfall pattern

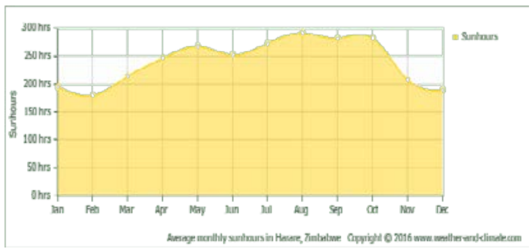


Figure 3. Hours of Sunshine in Zimbabwe

1.3 Mini grid application strategies

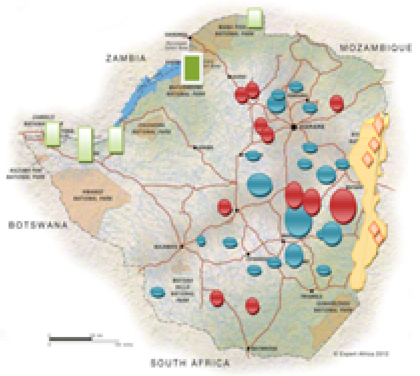
Globally, hydro, wind, and solar photovoltaic energy are at the top of renewable energy sources when considering installed capacity [8]. Where there is capital scarcity, smaller renewable generation encompassing lower capital injection may drive the economy, with options for retrofitting and snowballing as grid expansion resources and capital become available. This is a preferred option as opposed to waiting to build huge plants, which due to the economies of scale, would provide cheaper and readily available energy. Such strategies require a more extensive planning process and the mobilisation of capital may take longer or, altogether discourage the efforts. The mini-generation plants and the associated mini-grid options bring sustainable options that readily permit the participation of private investors and the beneficiary community at large [9].

1.4 Purpose and significance of this study

Electricity comes to the end user at a prohibitive cost which can be attributed to a strong dependence on centralized energy systems [9]. These systems are fed from high capital thermal and hydro-generators with collaborative transmission networks. This system, normally referred to as the energy grid, is usually expected to criss-cross a nation, thereby delivering the energy to all users and to most of the population. This conventional method requires huge capital investments for establishing the transmission and distribution grids that can reach the remote regions of a country. In developing countries like Zimbabwe, some areas remain largely un-serviced, with access to electricity being at 32% compared to the world trends which stands at 80%. It is the purpose of this review, to consider the various clean energy strategies, which can be readily harvested and afford the Zimbabwean population the much-needed electrical energy at a sustainable rate [10,11]. The option of mini-grids and micro-grids promptly leap up into prominence in this review because:

1. These do not require much capital investments, since they can be localised within the periphery of the generators and the consumers.
2. There is also an option for practicing smart grid strategies due to the size and possibilities of low capital investment.
3. Sustainability can be achieved through a systematic involvement of the beneficiary communities.
4. It's a step towards employment creation, industrial growth and indeed the improvement of the standards of living.
5. The mini-grid is immune to the maintenance challenges associated with the main national grid.
6. These mini-grids can eventually be snowballed, as resources trickle in, to create a shared power pool covering a sizeable area.

A due diligence program was conducted by the Rural Electrification Agent (REA) in Zimbabwe. The data was made available to potential investors for possible Private Public Partnership and Build-Own-Transfer approaches. The location of these sites is as shown on the attached Zimbabwe map on figure 4 [12]. These off-grid options represent an accumulated 311.68Mwh potential in power generation, an effective 14% of the national demand.



	Existing Dam sites with Mini Hydro Potential
	Proposed Dam sites with Mini Hydro Potential
	Existing Large Hydro Site
	Exiting Large Hydro Potential Site
	Proposed Mini Hydro Runoff river schemes Potential
	Area with Micro hydro potential (Runoff river schemes)

Fig. 4. Existing Dam sites with Mini Hydro Potential

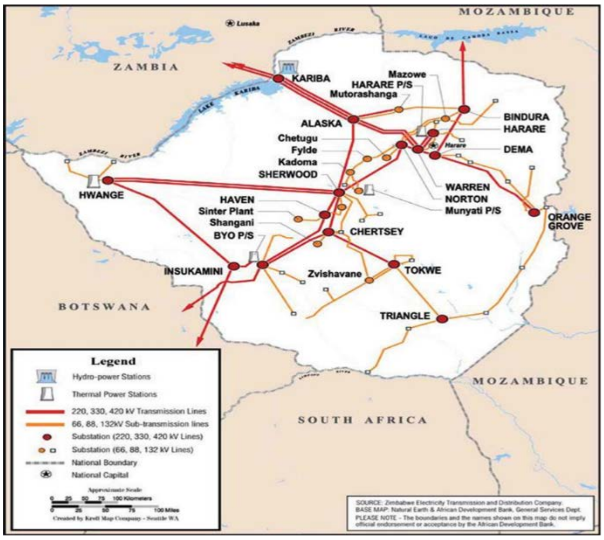


Fig. 5. Current distribution network (from African Development Bank)

The Zimbabwe National Energy Policy (NEP) has emphasized on permitting private investors participation with the objectives to:

Ensure availability, affordability and accessibility of electricity for all consumers

Provide a platform for adequate and reliable access to electricity to all at competitive prices

Allow access to IPPs and Private-Public Partnerships (PPPs), Private Public Associations (PPAs), and other joint ventures.

This NEP initiative reflects a marked opening for the possible investment into cleaner energy options, decentralised from the main grid. Although sounding lucrative and promising, there has been a limited number of private takers due to numerous uncertainties associated with governance issues in Zimbabwe. These options, when viewed as providing both sustainable solutions, environmental degradation mitigation and, humanitarian concern (for a nation with 39% stunted growth), it makes sense to review cheaper and effective strategies to get the energy to the population of Zimbabwe [14].

1.5 Long term objectives of the study

This study may not provide all the relevant data as required for a mini-grid establishment. It is however, expected to allow the accumulation of knowledge that will:

1. bring to attention the clean energy opportunities that can be utilised for the betterment of lives in the sub-saharan African region.
2. support the critical role of energy in economic growth and development.
3. lay the basis for simplified models that can be utilised to improve access to energy in Zimbabwe.

2. THEORETICAL FRAMEWORK

Neoclassical economics states that the quantity of energy available to the economy in any period is endogenous. This energy, might however be restricted by technical, biological, physical or chemical constraints. This view considers the extraction demands (biophysical constraints) or the installed extraction capacity (economic). The possible delivery times and process efficiencies play a critical role in this consideration [15]. This approach may dilute the role of energy as a critical input towards economic growth and productivity. Other theories, however, emphasize that energy is the only primary factor of production whilst capital and labor are secondary [16]. Geological and physical constraints therefore play a role at the rate of energy extraction and availability for production activities. All goods and services produced in any economy are therefore directly or indirectly linked to the energy used and pollution. The production process in any given economy can therefore be represented as an input–output model as advanced by Wassily Leontief and then adopted into the energy framework as done by Bruce Hannon and others [17,18].

2.1 Wassily Leontief model

The model shows the inter-dependency of different industrial sectors and their relationship within a given economy. It shows how the output from one sector becomes an input for the other sector. This conventional input–output analysis (IOA) developed by Wassily Leontief (1936) has found widespread use in analysing the energy in goods and the factors causing the changes in the consumption of energy. Using the IOA method, the summation of the output of an economy, expressed as X, can be derived from the amount of intermediate consumption, AX, and final consumption, Y:

$$X = AX + Y \qquad (1)$$

Equation 1 therefore advances the argument that all products, represent energy stored in one form or another [18]. This idea lends its strength from the theory of conservation of energy, which states that energy can neither be created nor destroyed but is transformed from one form to another.

Today, engineering practice is facing important challenges such as global warming, the scarcity of materials and the depletion of non-renewable resources. The spectrum of challenges also includes, technology, process digitalization, artificial intelligence, pollution and its effects on health [19]. All these issues must be considered. Engineers are expected to perform with high quality and contribute non-harmful and sustainable technology to solve challenges facing humanity today. Innovative approaches are therefore required to the practice of engineering as sustainability emerges as a key parameter in all engineering work and activities [20].

Sustainability is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987)

3. METHOD

There is a potential for over 300Mwh hydropower generation sites in Zimbabwe. While this is viewed as representing a financially intensive and ambitious target, the use of mini-hydropower set-ups, with the collaborative mini-grid systems can be utilised to service the accessible community [21]. This would automatically alleviate pressure on capital demands for energy and create sustainable green energy hubs which would power a target community [22]. Most of these sites are off the grid as seen in figure 5. The case of the Sebakwe dam, one of the potential candidate for study was used as a case study in advancing this view.

3.1 The Case for Sebakwe

The geography of Zimbabwe is such that the country is veined with several perennial rivers that flow all year round [23]. One such river which stretches for over 300km before confluence into another major river is the Sebakwe River. On this river, there is a 44m high dam wall, which was constructed over a span of two periods, in 1957 and in 1986. This wall, allows there to be a minimum head of 22 metres. Factors that were considered in identifying and selected for considering this location are:

1. Water supply – which is the primary source of energy and the dam wall is constructed on a perennial river.
2. Infrastructural makeup- the Dam wall has already been certified and availed by the Government of Zimbabwe as a suitable site for hydro-power generation.
3. Accessibility – there is a good road network leading to the site. 40km of the 58km is asphalt paved, while the remaining 18km is dirt though a maintainable road.

Sebakwe Dam is one of Zimbabwe's largest in-land dams with a surface area for body water of 2 600 hectares and an effective capacity of 265 730 million litres. This also presents an opportunity to investigate options for other renewable energy generation processes and retrofit for increased capacity. The envisaged general installation and set-up at Sebakwe Dam is as shown in the diagram given as figure 6.

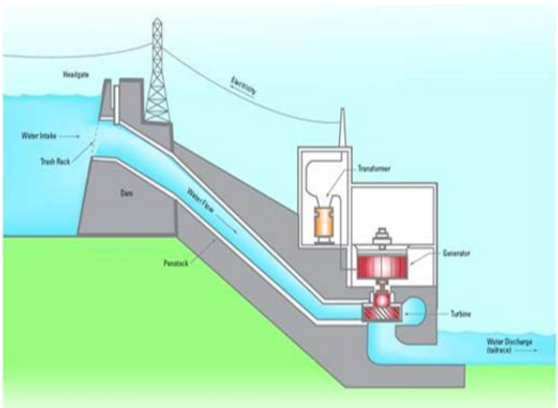


Fig 6. The proposed generation arrangement for Sebakwe. (Source: Eurasia News Online)

The basic process involves converting water potential energy into electrical energy.

The water accumulates, held back by a 40m dam wall as it flows from upstream during and after the rain season. Through the trash rack, and regulated by the head-gate, the water freely flows through the penstock. With this acquired kinetic energy, it passes through a hydro-turbine, which is then rotated and cause the excitations in the generator. The penstock, Head gate and trash rack are part of the dam design and civil adjustments that are to be done during the construction phase of the Power Plant. A typical penstock-turbine arrangement for a mini-hydropower plant is as shown below in figure 7.

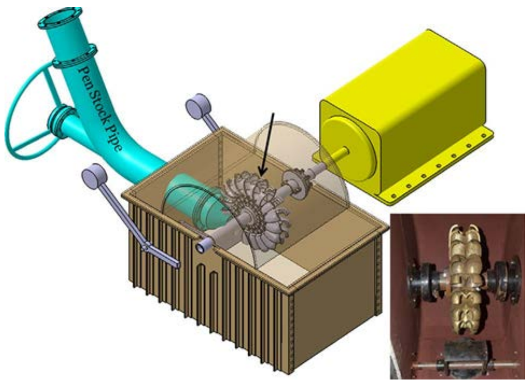


Figure 7. A typical penstock-turbine arrangement

The generated electricity is then sent to the distribution transformer for onwards transmission in the mini-grid [8,24]. After turning the turbine, the water is released into the river. This avails 3.59 Mwh of electricity to a community, which can be organised to engage into sustainable activities, retrofit options utilisation as well as developing a potentially viable production activity, having water and electricity at their door-steps.

3.2 Retrofit Opportunities

According to the climatic conditions, hours of daylight, there are possibilities of expanding this grid by adding solar energy harvesting farms within the confines of the grid. The ultimate envisaged grid network is as modelled in figure 8.

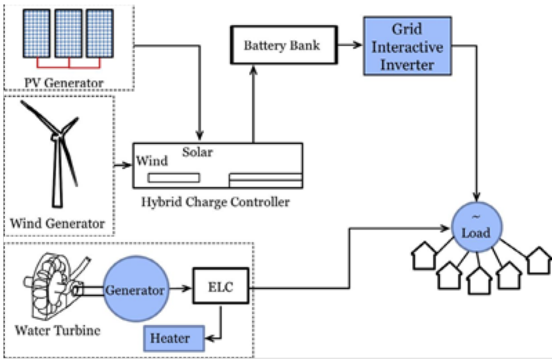


Figure 8. The Sebakwe Typical Mini-grid model with retrofit options of wind and solar.

4. CONCLUSION

The off-grid power generation options represent a disruptive option for sub-Saharan countries to bring about sustainable changes into most of the marginalised communities. This is because most of these opportunities are based along the off-grid positions, which could therefore entail a more meaningful impact onto the beneficiaries and the renewable clean energy options.

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