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ORIGINAL ARTICLE

Energy needs within the rural community in Makueni County, Kenya

Job Kitetu[1] | **Thomas Thoruwa**[2] | **Isaiah Omosa**[1]

[1]Kenyatta University, Nairobi, Kenya
[2]TVT Centre, Pwani University, Kilifi, Kenya

Correspondence
Job Kitetu, Kenyatta University, P.O. Box 43844 - 00100 Nairobi, Kenya.
Email: jobmuthini@gmail.com

Abstract

Literature shows that only 56% of Kenyan households had access to electricity, with rural areas having the lowest access rate at percent. The high cost of extending the power grid to remote areas and power losses on distribution are significant challenges facing rural electrification. In addressing power accessibility problems, especially in rural areas, there is a need for tapping hydropower generation through the invention and implementation of in-duct turbines to maximize the utilization of already existing pressurized water ducts that supply water in various parts of Kenya for hydropower generation. Makueni County is endowed with gravity-fed water ducts with high potential for hydropower which can innovatively be produced by application of in-duct turbines. This paper focuses on the assessment of energy needs and applications in rural areas. The research design was exploratory and experimental in nature. It was exploratory because, through an assessment, it sought to explore and identify the potential areas within the water supply lines for the production of hydropower to supply hydropower in Makueni County. It was experimental because the researcher developed (designed and fabricated) a hydro turbine for use in the production of hydropower from gravity water ducts of a diameter raging 100 mm. The research revealed that 62% (98) used solar power for lighting their homes, while 17% (28), 12% (20), and 8% (12) used lanterns, electricity, and kerosene lamps, respectively. Among the fuels assessed was firewood which was identified as the most used fuel at 89% (140). This was followed at a distance far by paraffin at 6% (9) of respondents. The households at 100% (158) identified electricity as a potential source of lighting for their household. The study recommends harnessing hydropower to enhance reach to 100% of the rural communities. The energy availability will provide opportunities for communities and institutions in rural areas to open their minds to business development and engage in income-generating activities like the rearing of poultry and the development of light industries like the gridding of maize and other cereals.

KEYWORDS

assessment, development, ducts, global positioning system, micro hydropower, open data kit

1 | INTRODUCTION

Hydropower is a mature and cost-competitive renewable energy technology (RET) that plays a strategic critical position in the electricity mix of the 21st century, accounting for more than 16% of global electricity output and around 85% of global renewable electricity. Literature review shows that hydropower capacity has been increasing steadily in the world, and over 160 nations depend on hydropower for socioeconomic development. Hydroelectricity offers various benefits over other electrical power sources, including high dependability, established technology, great efficiency (about 90% efficiency), very cheap operating and maintenance costs, flexibility, and substantial storage capacity.[1] Furthermore, given the instability of other renewable energy supplies, such as wind and solar, hydropower systems can aid in moderating oscillations between demand and supply. This is possible because of the wide range of hydropower plant sizes. Kenya's electricity generation is liberalized, with hydropower dominating the energy mix.[2]

According to Makueni County Government, the county is endowed with community water supply systems gravitating to settlement areas from the Volcanic Chyulu, Mbooni, Nzaui, and Kilungu Hills, hence if the potential hydro energy is developed, which would aid in reducing the energy deficit in rural areas by reaping green energy from small diameter (100–200 mm) community gravity water ducts.[3] This would also help with water pressure management by reducing pipeline ruptures and the associated repair expenses as well as disruptions in water supply to customers.[4] Furthermore, the development of such micro hydropowers (MHPs) in the local communities would increase awareness of the benefits associated with the use of RETs in Makueni County's power matrix, particularly through the harvesting of hydropower from small gravity water ducts.

Hydro energy is the use of gravitational force of falling or flowing water to generate electricity hence hydropower.[1] Twenty-two percent of the world's electricity production comes from hydropower installations, many of which are small hydropower schemes (SHPSs) which include small hydropower (SHP), MHP, and pico hydropower (PHP) systems.[2] The hydropower schemes are considered the source of energy that has a lower level output of greenhouse carbon dioxide (CO_2).[2] Hydropower is providing 19% of the world's electric power from both large and small power plants.[5] In Kenya, electricity supply is predominantly sourced from hydro and fossil fuel (thermal) sources. This energy generation mix comprises 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from biogas generation, and 0.4% from wind.[5] The generated electrical power (P) is calculated by

$$\text{Power} = \rho * g * H * Q * \eta, \tag{1}$$

where ρ is the water density, g is the force due to gravity, H is the water head, Q is the flow rate, and η is the efficiency coefficient. As per Equation (1), power is directly proportional to net head and flow rate.[6]

According to United Nations Industrial Development Organization and International Centre on Small Hydro Power,[3] electricity generation in Kenya is liberalized with hydropower dominating the electricity mix. Since the introduction of the feed-in tariff policy in Kenya in 2008, small-scale potential sites have been developed and serve well for the electricity supply to villages, small businesses and farms.[4] Apart from the few large and medium hydropower schemes operating in Kenya, others comprise SHPSs operating in Kenya as pico (<5 kW), micro (+5–100 kW), mini (+100–1000 kW), small (+1000–3000 kW), medium (+3000–30000 kW), and large (+30,000 kW) hydropower.[7]

The study sought to assess the needs and applications of energy for institutions and households in rural areas of Makueni County (Figure 1) and inform the exploration and production of hydropower from gravity ducts delivering water to community. According to Makueni County Government,[8] the county is endowed with community water supply systems running to the settlement areas from the hills of the Volcanic Chyulu, Mbooni, Nzaui, and Kilungu Hills.

Energy access is a fundamental driver of socioeconomic development, particularly in rural areas where traditional energy sources often fail to meet the demands of modern life. In Makueni County, Kenya, the energy needs of the rural community encompass various sectors, including household energy for cooking and lighting, as well as energy for agricultural and small-scale industrial activities. This literature review examines the current state of energy access in Makueni County, identifying key challenges and exploring potential solutions.

Household energy needs in rural Makueni County are predominantly met through traditional biomass sources, such as firewood and charcoal, which are associated with health risks and environmental degradation. A study by Ndiritu and Engola[7] highlighted that over 80% of rural households in Makueni rely on biomass for cooking, leading to significant indoor air pollution and respiratory issues. The adoption of cleaner cooking technologies, such as improved cookstoves and liquefied petroleum gas, has been promoted, but uptake remains low due to high costs and cultural preferences for traditional cooking methods.

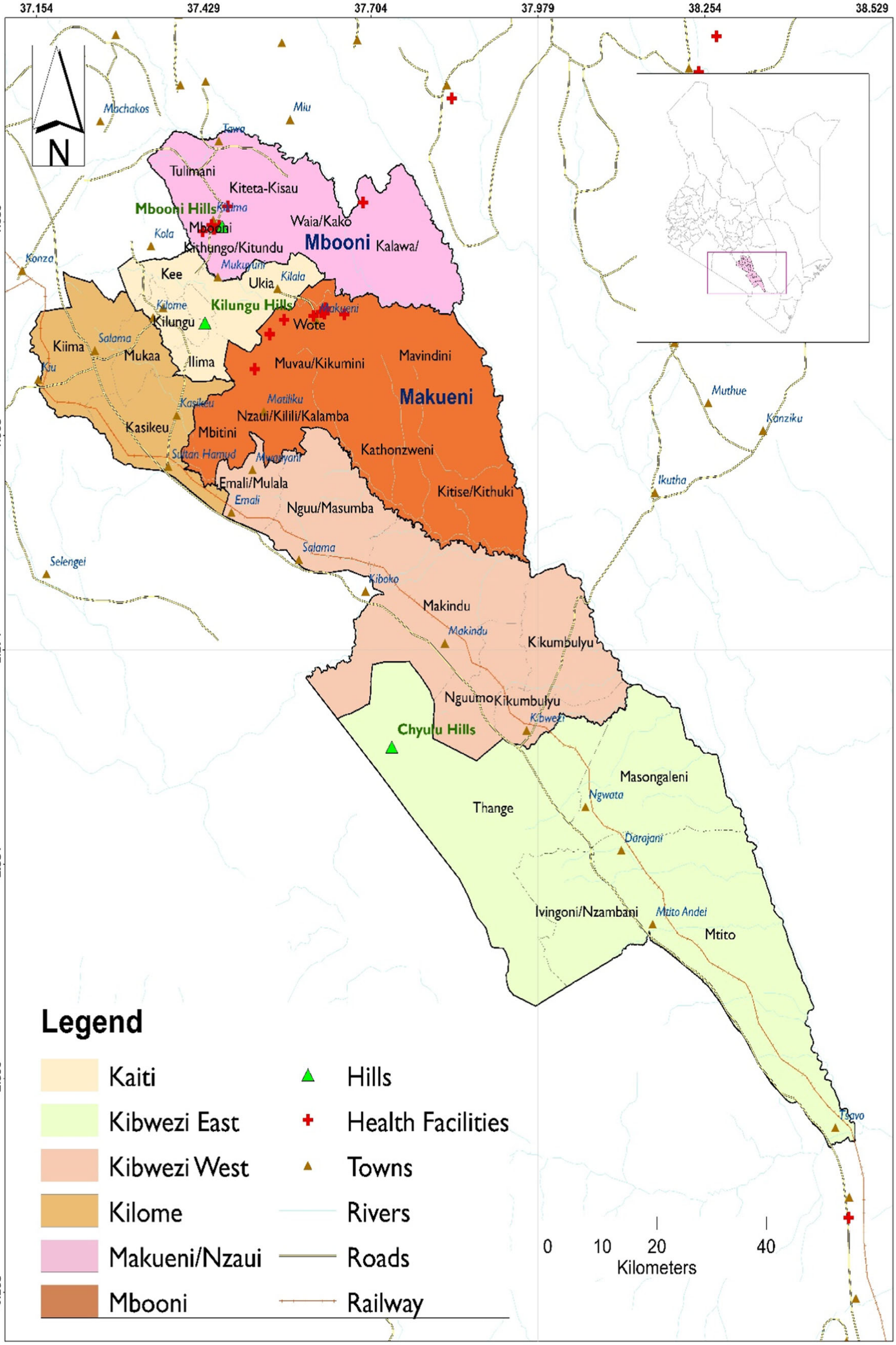

FIGURE 1 Map of Makueni County.

Agriculture is the backbone of Makueni County's economy, and energy access is crucial for enhancing productivity. Irrigation, mechanized farming, and post-harvest processing are energy-intensive activities that can significantly benefit from reliable energy sources. A study by Kamfor[9] emphasized the potential of solar-powered irrigation systems in improving agricultural yields and food security in the region. However, the initial investment costs and maintenance of these systems pose challenges for small-scale farmers.

Small-scale industries, including milling, welding, and carpentry, also face significant energy challenges in rural Makueni. These industries often rely on diesel generators, which are costly and environmentally unfriendly. According to a study by Mugo et al.,[10] transitioning to renewable energy sources such as solar and biogas can reduce operational costs and improve the sustainability of these enterprises. However, the adoption of RETs in small-scale industries is hindered by financial constraints and limited technical knowledge.

Renewable energy presents a viable solution to the energy challenges faced by rural communities in Makueni County. Solar energy, in particular, has gained attention due to its abundance and potential for off-grid applications. A study by Mutua et al.[11] demonstrated that solar home systems could significantly enhance energy access for rural households, reducing reliance on kerosene and improving lighting quality. Similarly, biogas technology offers an alternative for both cooking and electricity generation. Nyamai et al.[12] highlighted the success of community-based biogas projects in providing clean energy and managing organic waste in rural areas.

Despite the potential benefits of modern energy solutions, socioeconomic and cultural barriers impede their widespread adoption. High upfront costs, limited financing options, and lack of awareness about the benefits of RETs are significant obstacles. Additionally, cultural preferences and resistance to change play a role in the continued reliance on traditional energy sources. A study by Onyango and Njenga[13] found that community engagement and education are critical in addressing these barriers and promoting the adoption of clean energy technologies.

The Kenyan government has implemented various policies and programs aimed at improving rural energy access. The Rural Electrification Authority and the Kenya Off-Grid Solar Access Project are notable initiatives that seek to enhance energy infrastructure in rural areas. However, effective implementation and coordination among stakeholders remain challenges. According to Njiru et al.,[14] strengthening institutional frameworks and fostering public–private partnerships are essential for achieving sustainable energy access in rural Kenya.

Energy access is a critical factor for socioeconomic development, particularly in rural areas where traditional energy sources are often insufficient or unreliable. In Makueni County, Kenya, the energy needs of the rural community are multifaceted, encompassing household energy for cooking and lighting, as well as energy for agricultural and small-scale industrial activities. Despite numerous initiatives aimed at improving energy access in rural Kenya, significant gaps remain, and many households continue to rely on inefficient and unsustainable energy sources.[1]

Numerous studies have explored the energy challenges in rural Kenya. For instance, Mulu et al.[15] examined the impact of solar energy adoption in rural households, highlighting its benefits in reducing dependency on traditional biomass. Similarly, Mugo et al.[16] focused on the implementation of biogas technology in rural areas, noting improvements in energy security and environmental sustainability. However, these studies often concentrate on specific energy solutions without providing a comprehensive analysis of the broader energy needs and preferences of rural communities. Additionally, they tend to overlook the socioeconomic and cultural factors that influence energy adoption and usage patterns.

Several gaps in the existing literature warrant further investigation. First, there is a lack of comprehensive studies that assess the diverse energy needs of rural communities in Makueni County across different sectors, including household, agricultural, and small-scale industrial energy requirements. Second, the socioeconomic and cultural barriers to adopting modern energy technologies are not sufficiently addressed. Understanding these barriers is crucial for designing effective energy interventions. Third, there is limited research on the long-term sustainability and scalability of different energy solutions in rural settings. Most studies focus on short-term outcomes without considering the long-term impacts on energy security and socioeconomic development.

2 | METHODOLOGY

The assessment of energy needs in Makueni County was conducted with a focus on leveraging existing community water supply systems to explore the potential for MHP generation. The county is endowed with water supply systems originating from several highland areas, including the Volcanic Chyulu, Mbooni, Nzaui, and Kilungu Hills. These systems supply water to settlement areas through ducted projects, which had not yet been utilized for hydro energy due to funding constraints and low awareness of the relevant technologies.[17]

2.1 | Study sites and data collection

The study targeted specific gravity water schemes: Kweleli and Manooni in Nzaui Sub-County, and Ikokani and Mulima in Mbooni West Sub-County. These schemes feature pipelines with diameters ranging from 50 to 200 mm, and the assessment focused on sloped areas of the pipelines where there was a significant height difference between the start and end points, with a minimum height difference of 40 m. The slope heights were measured using mobile phones equipped with global positioning system (GPS) mapping tools to ensure accurate data collection.

2.2 | Survey instrument and data collection

To accurately identify the energy needs of the community, the researcher developed a detailed questionnaire using the open data kit (ODK) platform. This digital tool allowed for efficient data collection and management. The questionnaire was administered to selected sites along the water ducts that had potential for MHP generation. The survey specifically targeted areas within a 500-m radius of these potential sites, encompassing institutions, shopping centers, and households.

2.3 | Sample size and participant selection

The survey involved a total of 158 households and 21 institutions. Participants were chosen based on their proximity to the potential MHP sites and their involvement in activities that currently relied on paraffin, diesel, petrol, and wood energy. Key economic activities in the county, such as cotton processing, fruit processing, and small-scale trading, were also considered due to their significant energy requirements.

2.4 | Data analysis

The collected data were analyzed to assess the current energy usage patterns and to determine the feasibility of implementing MHP systems. The analysis focused on identifying the primary power consumers within the 500-m radius of the potential hydropower sites, including primary schools, shopping centers, cyber cafes, and households. The aim was to understand the extent of energy needs and the potential impact of transitioning to MHP systems on these communities.

3 | RESEARCH RESULTS AND DISCUSSIONS

3.1 | Energy needs in rural areas

Assessment surveys on community activities which needed energy and the cost of energy used to carry out the activities had varying characteristics. The assessment focus was on the activities in schools, shopping centers, cyber cafes, and households which were using paraffin, diesel, petrol, and wood energy for operation while considering economic activities in the county, including cotton processing, fruit processing, and maize milling that required power to operate.

3.1.1 | Social demographic information

According to Makueni County Government,[18] the response order effects are stronger for respondents with less formal education. This gives more authenticity to the responses provided by respondents on energy needs since a high percentage of the 158 household respondents had formal education, as shown in Figure 2.

A high percentage of respondents were educated, with 44% (70) of sampled respondents having Secondary education, 38% (60) having Upper Primary education, and 2% (3) with Lower Primary education level. In all, 13% (20) had other levels of education, such as college and polytechnic education. Only 1% (1) had nursery education as the highest level, while another 2% (4) had no formal education at all.

3.1.2 | Household and institutions energy

Source of energy for lighting

A total of 158 households along the pipes had representatives to which the research questionnaire was administered. As in Figures 3 and 4, among the sampled households, 62% (98) used solar power for lighting their homes, while 17% (28), 12% (20), and 8% (12) used lanterns, electricity, and kerosene lamps, respectively. The least used source of home lighting was a generator at 1% (1) usage. However, among the sampled institutions, hydropower and lantern were the main source of lighting at 33% (7) each. In all, 19% (4) and 14% (3) use generator and lamp, respectively, for lighting purposes.

Source energy for cooking

The rural community in Makueni County cook food using various sources of energy. Among the fuels assessed was firewood which was identified as the most used fuel at 89% (140). This was followed at a distance far by paraffin at 6% (9) of respondents. Biogas was least

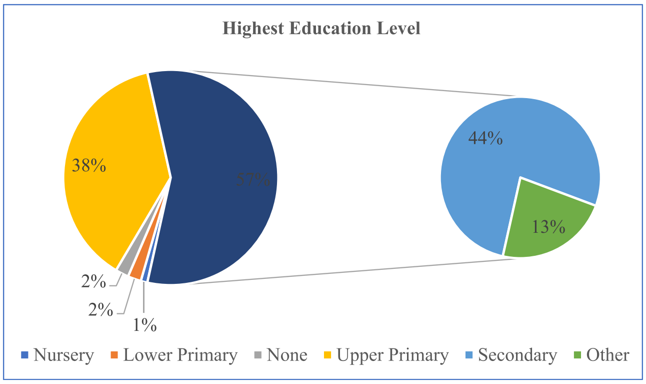

FIGURE 2 Education level.

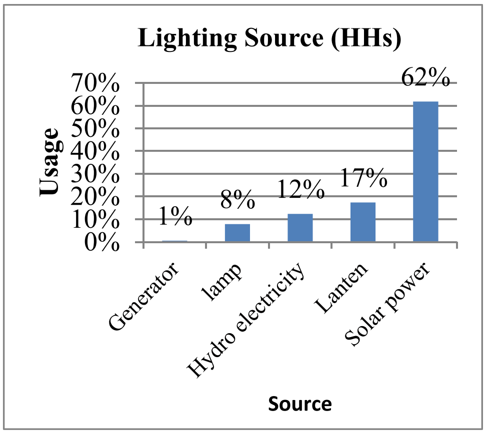

FIGURE 3 Lighting source. HHs, households.

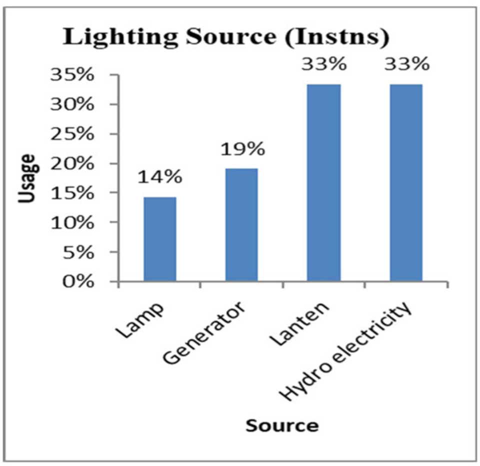

FIGURE 4 Lighting source.

used at 1% (1). This may be attributed to most households having their livestock at free range rearing, the high cost of developing the biogas system, and the lack of knowledge of the installation and benefits of biogas systems. The other sources of fuel were gas cookers and

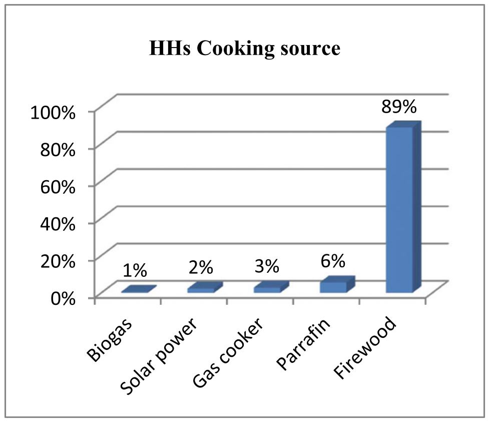

FIGURE 5 Cooking energy source. HHs, households.

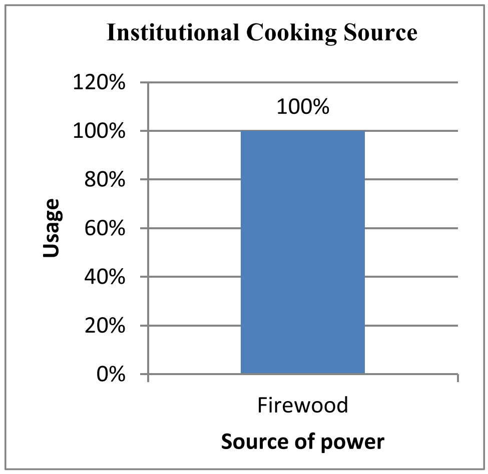

FIGURE 6 Cooking energy source.

solar power at 3% (4) and 2% (3), respectively. All the institutions subjected to the ODK survey indicated that the only source of energy for cooking was firewood. This is as in Figures 5 and 6.

3.1.3 | Other activities requiring energy

When energy is available, the rural community could use it for other uses other than the traditional ways; hence, the survey targeted to establish other ways in which available energy would be used. In Figures 7 and 8, the respondents specifically identified chicken rearing as the main other activity which require power in their households at 30% (48) while maize flour making was at 9% (15). A total of 20% (4) institutions were clear on other needs for power where they would apply it if available, thus chicken rearing an income-generating activity (IGA).

In all, 61% (97) of the households and 80% (17) of the institutions opted for a wait-and-see situation, after which

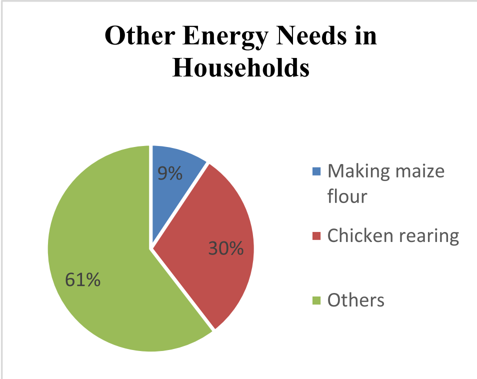

FIGURE 7 Other needs for energy.

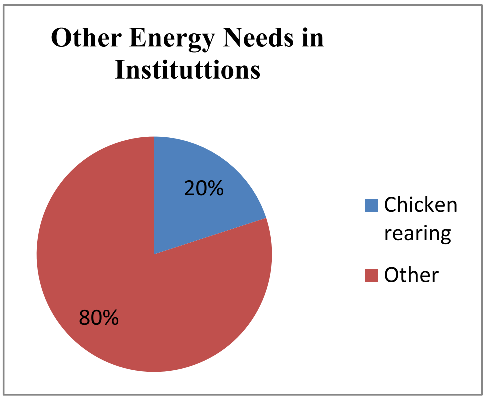

FIGURE 8 Other needs for energy.

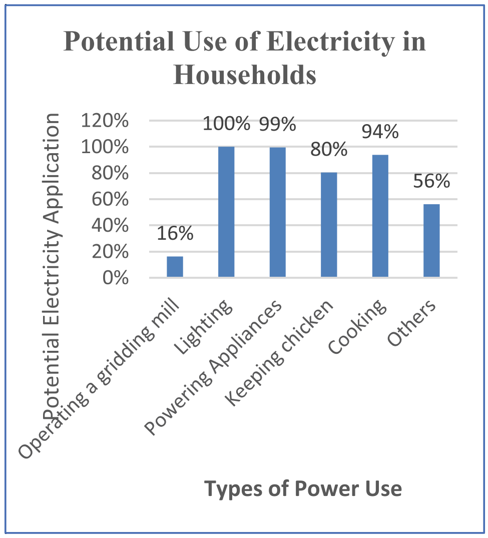

FIGURE 9 Potential use of electricity.

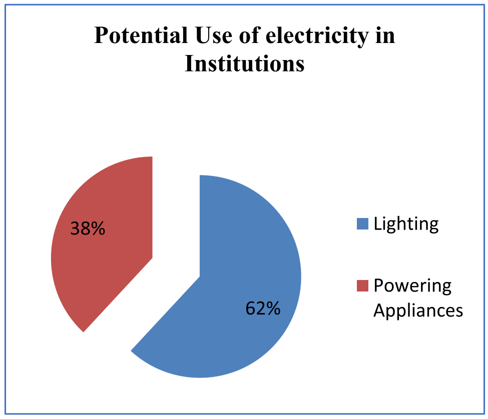

FIGURE 10 Potential use of electricity.

they would decide on a power application once available. However, on further inquiry on the potential use of availed electricity (hydropower), the information in Figures 9 and 10 reveals that the households at 100% (158) identified electricity as a potential source for lighting for their households, 99% (157) of all sampled households would use it for powering appliances, 94% (148) for cooking, and 16% (26) preferred to use electricity for a maize grinding mill. For institutions, Lighting and powering appliances were identified as the potential uses of electricity in institutions if it was made available. Lighting was identified as the leading potential use at 62% (13), while powering appliances was at 38% (8).

4 | POTENTIAL ENERGY PRODUCTION

The heights of slopes start and end points along the pipelines were measured by use of mobile phones and GPS and had 33 varying sections heads/heights ranging from 14 to 183 m. With the application of the formula: $P = \rho * g * H * Q * \eta$, where P is the power in W, ρ is the water density in kg/m^3, g is the force due to gravity in m/s^2, H is the water head/height in m, Q is the flow rate m^3/s, and taking efficiency coefficient η to be 0.7, the different sections were estimated to produce power ranging from 0.59 to 23.63 kW hence harnessing the potential hydropower along each of the pipeline sections would help reduce the power deficit in the institutions and households around them.

The maps of the four (4) pipelines of Manooni, Mulima, Ikokani, and Kwelelei are as shown in Figures 11–14.

As shown in Figure 15, out of the 33 identified potential sections, 13 sections were along Manooni, nine were along Mulima, eight were along Ikokani, and three were along Kweleli water scheme pipelines. While applying an efficiency coefficient of 0.7 in the power production formula, six (6) potential sections had a

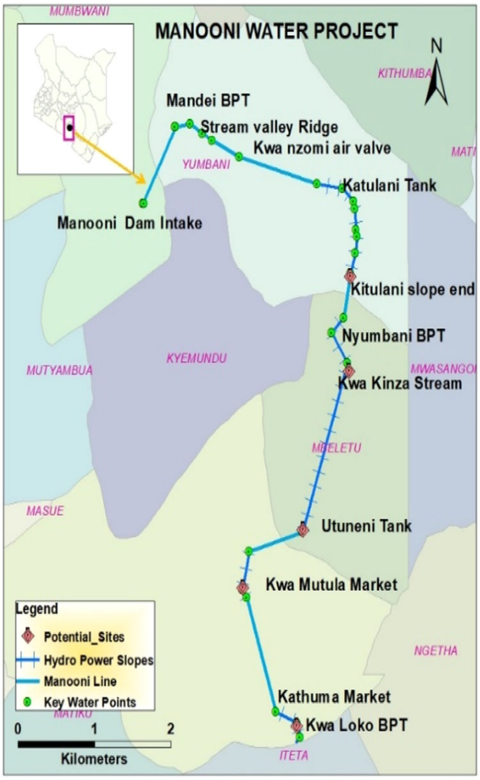

FIGURE 11 Manooni water project map.

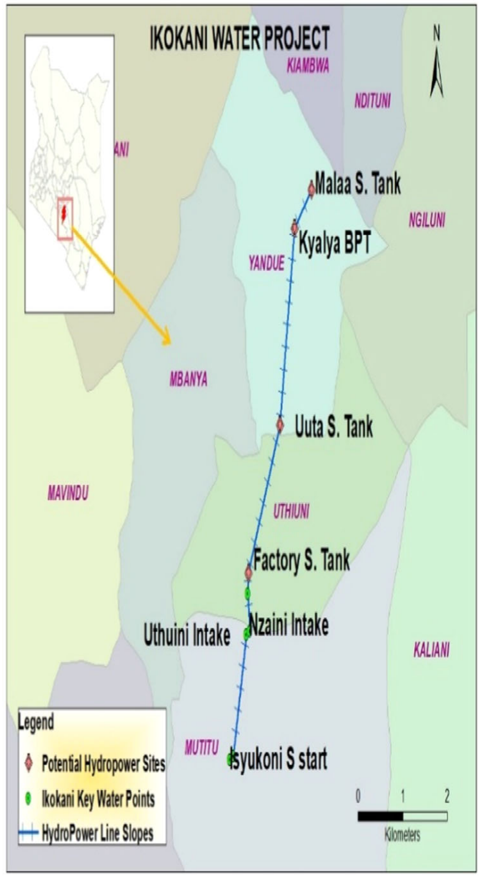

FIGURE 13 Ikokani water project map.

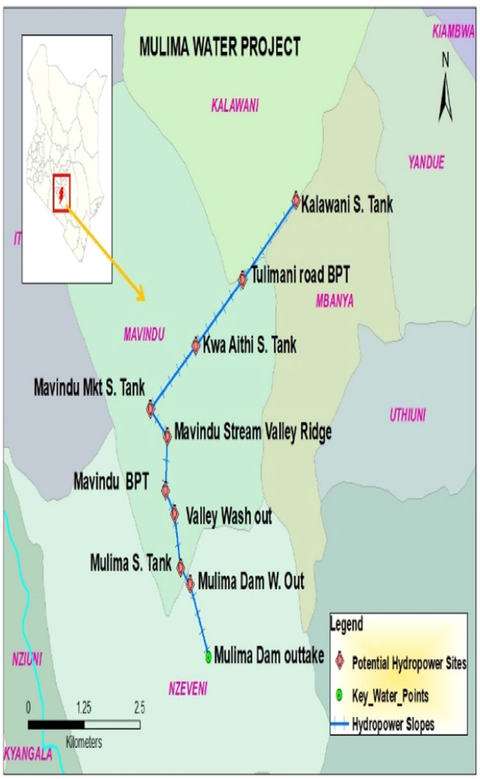

FIGURE 12 Mulima water project map.

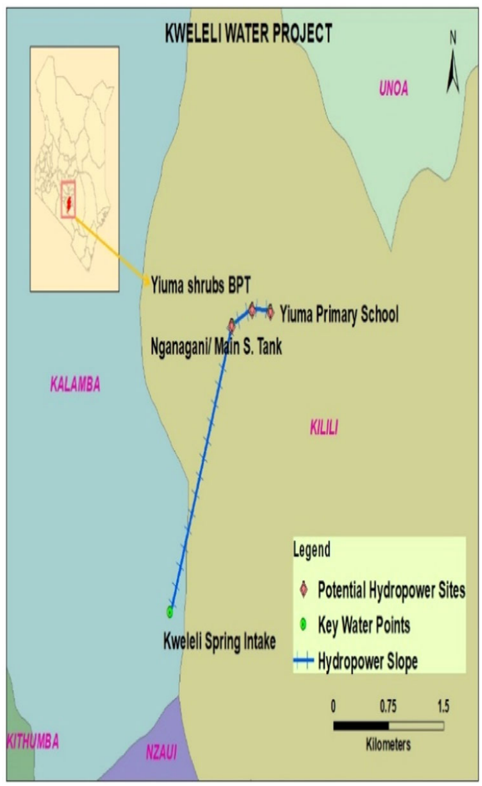

FIGURE 14 Kweleli water project map.

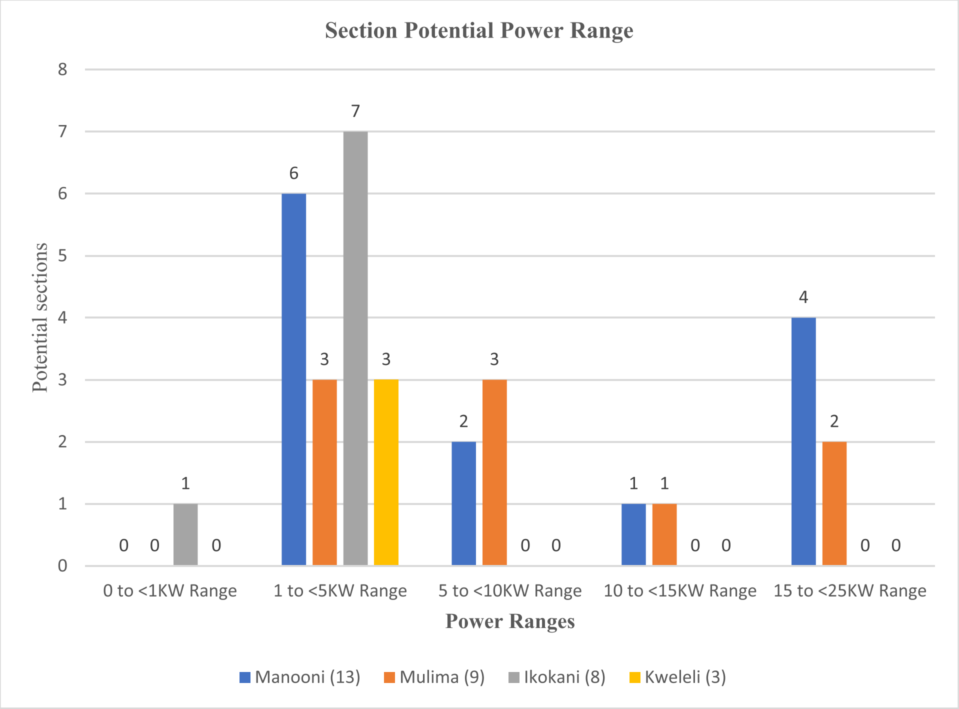

FIGURE 15 Potential power ranges within pipeline sections.

power range of 15 to <25 kW, two (2) had a power range of 10 to <15 kW, five (5) had a power range of 5 to <10 kW, and nineteen (19) had a power range of 1 to <5 kW, while only one (1) had power production was in the range of 0 to <1 kW.

5 | CONCLUSION AND RECOMMENDATIONS

The survey revealed that a significant portion of the community's energy needs are currently met through unsustainable sources, such as paraffin and wood. Institutions like primary schools and shopping centers were identified as major energy consumers that would benefit from a more reliable and sustainable power source. The analysis indicated that the installation of MHP systems could significantly reduce the reliance on these traditional energy sources, thus promoting environmental sustainability and economic development in Makueni County.

The methodology employed in this study provided a comprehensive assessment of the energy needs within the rural community in Makueni County. By leveraging digital tools like the ODK platform and GPS mapping, the researcher was able to collect accurate and relevant data to inform the feasibility of MHP systems. The findings underscore the potential benefits of MHP in meeting the energy needs of the community, highlighting the importance of addressing funding and awareness challenges to promote the adoption of environmentally friendly renewable energy solutions.

In the world allover and in Kenya particularly, there are many existing gravity-fed water pipelines with potential energy. The potential energy needs to be exploited by the use of innovative technologies like in-duct turbines. Hydropower is one of the affordable sources of energy hence needs to be harnessed wherever it is available and this will enable rural communities that are yet to be 100% connected to power to access adequate hydropower. By development of MHP/PHP, energy will be available, hence making the communities and institutions in the rural areas venture into IGAs like the rearing of poultry and development of light industries, including gridding of maize and other cereals, hence opening their minds to business development.

Renewable energy and more so production of hydropower from ducts will provide a paradigm shift to the rural communities whose 89% of them in Makueni County use firewood for cooking. The use of firewood for cooking and other domestic applications exacerbates deforestation and reduces rainfall. The research has shown that 63% of rural households use paraffin-fueled lanterns for lighting; hence, the application and use of renewable energy for lighting will provide an opportunity for the rural community and institutions to disengage from the use of lanterns and paraffin lamps, which are very smoky and make the user very vulnerable to respiratory-related sicknesses.

More studies are recommended on improved technologies of harnessing hydropower from the existing hills in Kenya with a focus on the production of MHP/PHP from pipes less the 50-mm diameter, which are very common in rural areas.

ORCID

Job Kitetu http://orcid.org/0009-0009-3719-712X

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