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Sustainability Challenges and Opportunities of Generating Biogas from Water Hyacinth in Ndunga Village, Kenya

Antony N. Kamau, Paul Njogu, Robert Kinyua and Mohamed Sessay

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Dr. Joël Houdet
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5. Sustainability Challenges and Opportunities of Generating Biogas from Water Hyacinth in Ndunga Village, Kenya

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Abstract

Recent studies show possibilities of producing bio-energy from water hyacinth thus generating avenues for research, technological development and marketing of its energy products. As the search for alternatives to clean energy sources intensifies in this age of industrialization, coupled with the increasing energy costs on conventional energy sources, water hyacinth holds a strong promise in the production of clean renewable energy. Though it possess significant benefits, there is need to understand the viability and sustainability of such a technology through assessment of likely socio-economic and environmental impacts to the local community and environment in general. The study was undertaken to determine potential of water hyacinth *E. crassipes* as a suitable source of renewable energy in an effort to pursue alternative approaches in the management of water hyacinth in Lake Victoria. The study was carried out in a small village called Ndunga, in three phases, employing both descriptive and analytical data collection techniques. The study established that the utilization of water hyacinth to yield biogas adds value to the noxious weed, while the bi-product slurry can be added in to agricultural soil, as a bio fertilizer, to boost its nutrient composition. As a result, this technological development is viewed as a breakthrough in the renewable energy sector through bridging present energy provision gaps for rural communities living within ecosystems infested by water hyacinth, whereas contributing to controlled management of water hyacinth through increased harvesting.

Key Terms – Biogas, Lake Victoria, Renewable Energy, Water Hyacinth.

1. Introduction

1.1 Background

Water Hyacinth is a free- floating flowering weed whose origin is in South America. It is an aquatic freshwater plant biologically known as *E. crassipes*, belonging to the family Pontederiaceae, related to the lily family (*Liliaceae*). It is known to reproduce both asexually and sexually by seed propagation, and remains viable for up to 20 years making it difficult to control (Center et al. 1999). In aquatic systems, water hyacinth is normally distributed by water currents, wind and boats among others agents. It was first introduced as an ornamental crop species in many countries more than a century ago, and later realized to be an invasive species due to its adaptability to a wide range of fresh water ecosystems causing interference to human activities and adversely affecting flora and fauna making it to be considered as a noxious weed in many parts of the world that significantly endanger the livelihoods of millions of poor people in the tropics. Also, the invasion of water hyacinth in water ways is reported to cause challenges in hydro-electric generation, irrigation and as well as increased in water loss in aquatic systems through evapo-transpiration. The weed provides breeding grounds for schistosome (bilharzia)-carrying snails and malaria-carrying mosquitoes. In Lake Victoria for example, the infestation currently covers 12,000 ha and is affecting the livelihoods of more than 40 million people in Kenya, Tanzania and Uganda (Center et al. (1999). Available reports from media agencies indicate a 70% decline in economic activities at the Kenyan port of Kisumu as a result of the water hyacinth choking the port and fish landing grounds Bugaari et al. (1998). As a result, huge amount of resources and efforts have been invested, to manage its growth with world leading environment conservation institutions like the World Conservation Council (IUCN), the United Nations Environment Program (UNEP), and the Ramsar Convention on Wetlands classifying water hyacinth as the world's most destructive plant species. The cost of damages related to water hyacinth proliferation in aquatic ecosystems is estimated to be in the billions of dollars each year.

1.2 Presence in Africa

In the developing world, it has been used in traditional medicine and even used to remove toxic elements from polluted water bodies (Center et al., 1999). Due to its ability to grow very fast and depleting nutrients and oxygen rapidly from water bodies, adversely affecting flora and fauna, it has been considered as a noxious weed in many parts of the world and significantly endangering the livelihoods of millions of poor people in the tropics. The influx of water hyacinth has resulted in serious socioeconomic and environmental problems for millions of people in riparian communities. Normally, the weed proliferates to form extensive floating mats that cause complete blockage of waterways making fishing and other water related human activities such as recreation and navigation very difficult. Also invasion of water ways by water hyacinth is reported to cause challenges in hydro-electric generation, irrigation and as well as increased in water loss in aquatic systems through evapo-transpiration. The weed also provides breeding grounds for schistosome (bilharzia)-carrying snails and malaria-carrying mosquitoes. The cost of water hyacinth infestation for countries in the region is estimated to be of the order of billions of dollars. For example, in Lake Victoria, the infestation currently covers 12,000 ha and is affecting the livelihoods of more than 40 million people in Kenya, Tanzania and Uganda (Center et al. 1999). By the end of 1997, media agencies reported a 70% decline in economic activities at the Kenyan port of Kisumu as a result of the water hyacinth choking the port and fish landing grounds (Bugaari et al., 1998).

According to Shoeb and Singh, (2002) report, it is indicated that under favorable conditions water hyacinth can achieve a growth rate of 17.5 metric tons per hectare per day. In Kenya, although water hyacinth is known to have been kept in Nairobi and Mombasa as an ornamental plant since early 1957, it appeared in the natural water systems of Lake Victoria in the late 1980s. Lake Victoria has a surface area of 68,800 Km^2 and an adjoining catchment of 184,000 Km^2, and is the world's second largest body of fresh water, second only to Lake Superior (Freilink, A., 1991). The lake touches the equator in its northern reach enclosing innumerable small, shallow bays and inlets, many of which include swamps and wetlands which differ a great deal from one another and from the off-shore environment of the lake. Kenya, Tanzania and Uganda control 6, 49, and 45%, of the lake surface respectively (Bugaari et al., 1998). The gross annual economic product from the lake catchment is in the order of US$3–4 billion, supporting an estimated population of 25 million at per capita annual incomes in the range US$90–270 (Center et al. 1999). It provides for the livelihood of one third of the population in the three countries, and about the same proportion of the gross domestic product. Economically, the lake catchment is principally characterised by fishing activities with significant subsistence agricultural activities been practised. In Kenya and Uganda, the areas of coffee and tea plantation in the lake's catchment are a significant part of those nations' major agricultural exports.

The lake is also seen as a source of food, energy, drinking and irrigation water, transport, and as a repository for human, agricultural and industrial waste. The population around the riparian communities has been noted to grow fast, leading to increased resource use and conflict around the Lake Basin, rendering the lake as environmentally unstable. The lake ecosystem has undergone substantial changes which have accelerated the dominance by the toxic blue–green algae (Twongo and Balirwa, 1995). The frequency of water-borne diseases has increased. Water hyacinth has choked important waterways and landings (Twongo and Balirwa, 1995). Massive depletion of oxygen in the deeper waters of the lake threatens the artisanal fisheries and biodiversity. Scientists advance two main hypothesis for these extensive changes. First, the introduction of Nile Perch as an exotic species some 30 years ago has altered the food web structure. The second hypothesis is that nutrient inputs from its catchment are causing eutrophication, creating favorable conditions for proliferation of Water hyacinth. Thus, although the lake and its fishery have shown evidence of dramatic changes in the past three decades, the problems have arisen mainly as a result of human activities in the lake basin. Efforts among various actors have been put in place all over Africa to remove water hyacinth from waterways. This is been done by hand, by machine, using chemical pesticides and biological control methods. Though great efforts and resources have been directed towards its complete eradication continues to be elusive with discrepancies among policy makers, environmental agencies and research scientists on the best way to control this invasive species and the practical benefits that can be obtained. The Convention on Biological Diversity recommends that each contracting party take measures to prevent the introduction of exotic species and to control or to eradicate those that threaten ecosystems, habitats or species. Hence concerns over introduction of other sustainable control measures continue to be explored, forming the rationale to this study. Achieving solutions to possible shortage in fossil fuels and environmental problems that the world is facing today requires long-term potential actions for sustainable development. In this context, renewable energy resources appear to be one of the most efficient and effective solutions.

1.3 Potential of Water Hyacinth for production of renewable energy

In efforts to manage water hyacinth, recent studies by Bhattacharya and Kumar (2010), report possibilities of producing energy (bio-fuels) from the water hyacinth. This has generated ample

avenues of research, development and marketing of the hyacinth's energy products. As the search for alternatives to clean energy sources intensifies in this age of modernization and industrialization, fuelled by increasing energy costs and needs, water hyacinth holds a strong promise in the 21st century. In Kenya for example, growth in the industrial sector accounts for more energy requirement, hence the need to generate more energy at a lower cost to support the energy needs of the marginalized groups and rural communities who play a big role in the growth of an economy. Currently, Kenya's major source of energy for commercial use include petroleum, syngas and hydropower electricity, while wood fuel and charcoal provides energy for majority of rural communities and the urban poor. According to Vision 2030, the government remains committed to continued institutional reforms encouraging innovation in the energy sector (Kenya Vision, 2030). It is in this perspective that efforts by various actors in the energy sector in Kenya and around the world have intensified research to generate biogas using water hyacinth. For example, a partnership between Jomo Kenyatta University of Agriculture and Technology through its Institute of Energy and Environmental Technology and Japan International Cooperation Agency has set up a prototype facility at Ndunga beach to assess biogas production using water hyacinth with the objective of scaling up renewable energy production for rural development though the 'Bright Project'. Following concerns over introduction of other sustainable control measures to the water hyacinth menace, the emergence of this technology that seeks to use water hyacinth for biogas production is not only seen as a breakthrough in clean energy revolution but also a significant measure in the control of the invasive species in fresh water ecosystems. This is a form of technology that upholds the concept of waste to wealth in enhancing sustainable development.

This study hypothesized that biogas production using water hyacinth enhances sustained management of water hyacinth in Lake Victoria and promotes socio economic activities for the community living in Ndunga beach in the lake region.

2. Study objective

The study seek to identify the social, economic and environmental impacts of utilizing water hyacinth as feedstock for biogas production in Ndunga, to determine the viability and sustainability of this technology.

2.1 Study questions & methodology

In doing so, the study focused on answering 3 key research questions notably:

1. How has water hyacinth affected the livelihoods of the community in Ndunga beach?

2. Does water hyacinth hold significant value as a source of renewable energy to address energy gaps in Dunga and to warrant adoption of the technology by the community?

3. How environmentally sustainable is this technological development?

A preliminary study of Ndunga village was carried out to map out all stakeholders relevant to this study leading to the identification of study respondents. The study focused on the locals, the business community, government as well as the non-governmental organizations whose activities revolved around the lake management. Among the respondents identified were local community members who included fishermen, farmers, small enterprise owners, employees of government

bodies operating in the region as well as officials of non-governmental organizations operating in the area; all of whose activities have been affected by water hyacinth infestation of the lake in one way or another. A total of 50 respondents, an estimate of 16% of Ndunga's population, were interviewed, with a response rate of 96% of the respondents.

Stratified random sampling procedure was then used to identify sample respondent. Data was collected using questionnaires administered through interviews schedules. Focus group discussions were also held to collect data that would otherwise not be captured from individual interviews. This technique was helpful in profiling social, economic and environmental issues related to water hyacinth invasion of the lake, obtain information on potential risk factors and benefits associated with this technological development in water hyacinth management and renewable energy development. The choice of data collection method to specific respondents was based on how best the respondent was able to provide information effectively and conveniently. Desktop review of relevant literature was done to acquire information on benefits of similar technologies applied elsewhere in rural setups world.

Satellite images were also acquired to show hyacinth spatial distribution and the dynamic of water hyacinth over a specific period of time. The study emphasised on cost-benefit relationship analysis of the findings as the overarching factor in determining the viability and sustainability of this technological development. Qualitative and quantitative data analysis methods were employed in the study. Frequency distribution tables and measures of central tendency (mean), measures of variability (standard deviation) were used to generate logical information from collected data. The analysis was aided by the use of SPSS software, which produced the various statistical results. Tables, charts and other diagrammatic representation of data were used to present the data, summarize responses for further analysis and interpretation of findings as well as facilitate comparison of various variables.

3. Results and discussions

3.1 Study Site Characteristics

Located on the eastern side of Kisumu, Dunga beach exhibits a set of unique characteristics that determines its identity and the behaviour of its people. Physically, the beach forms a gulf that boarders Lake Victoria from the eastern side of Kisumu. This largely influences fishing as the main economic activity and source of livelihood for majority of the community members. Also, as an enclosed community with only one exist route, Dunga community still upholds traditional practises common among the Luo community making it a distinct site for social studies. It is in this regard that many researchers have in the past used Dunga community for various social related studies. Close proximity to the lake gives Dunga ease access to the lake which has contributed to increased ecotourism activities, and related studies in the region. However, Dunga faces a myriad of challenges with regards to the level of development compared to neighbouring communities due to limited resource allocation. As the study established, majority of the community do not feel the government's presence neither enjoy any government incentives. In fact, according to Kisumu district data on resource distribution and expenditure, (2009), this region received the least amount of funding for development purposes, of which no physical evidence of development initiatives could be accounted for.

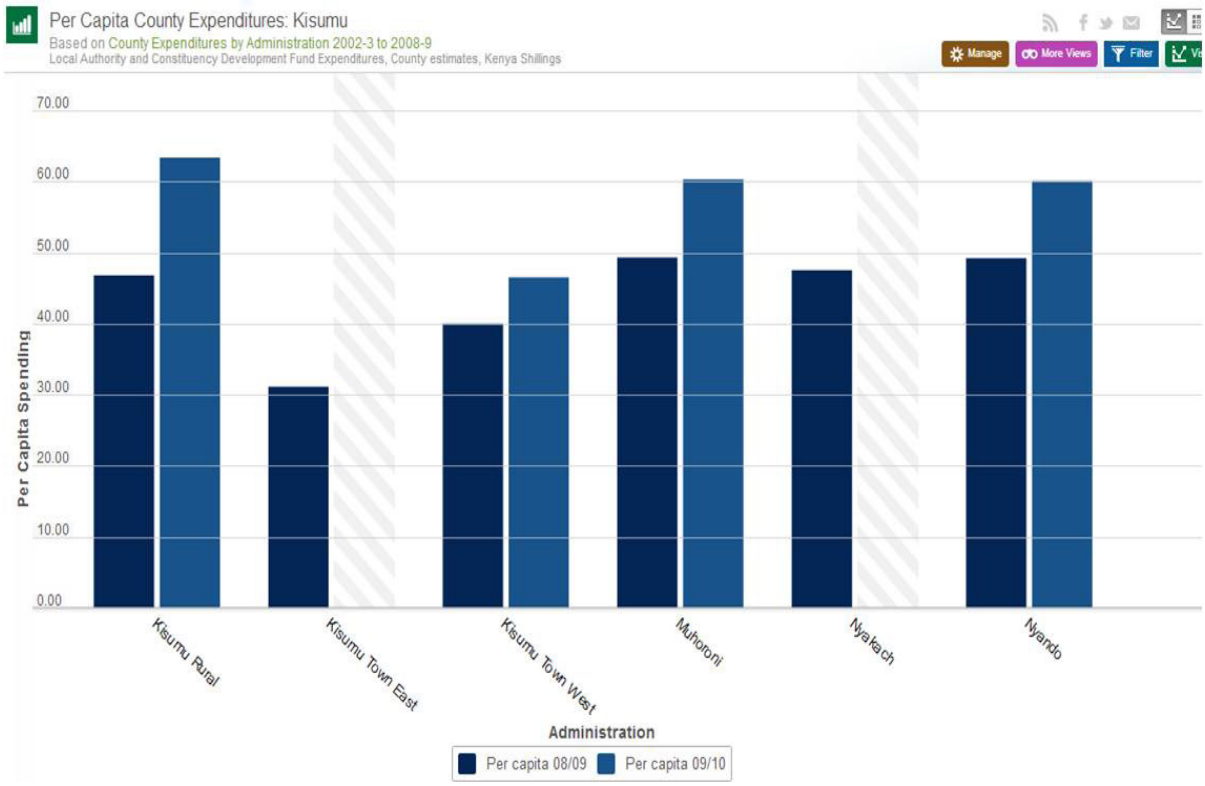

Figure 1:2008/2010 Kisumu County Expenditure Index Per Region

This has resulted to marginalization of the local community characterised by the significant level of illiteracy of the local population, limited access to social amenities, poor housing structures and dire sanitary conditions of the local community, as well as poorly maintained access roads. In pursuit for survival, a number of small enterprises, in the form of hotels, general merchandise and workshops have been set up by locals to provide important basic goods and services as well as a source of income for the community. These enterprises have also contribute to a number of job creation opportunities for a few members of the community. However, with the devolved system of government coming into place communities remained hopeful of better days to come though nothing much had be done by the time this study was undertaken. As a small community, Dunga is estimated to host approximately 300 people with around 50 homesteads spread across the village. This is according to Kisumu county census data of 2009. The study established that the population has over the years significantly reduced due to reduced opportunities for economic activities. This is linked to water hyacinth invasion of the lake given that Dunga is widely known as a fishing community. Luo, an ethnic community that represents a significant third of Kenya's population, dominates Dunga village as the major ethnic group at approximately 99.9% of the population.

3.2 Social Economic Status of Dunga community

To understand the socio-economic status of the community, the study focussed on literacy levels, major economic activities practised by the local community and employment opportunities available as key indicators of economic and social wellbeing of Dunga community.

3.3 Literacy

Literacy level of the Dunga community was assessed to be significantly low and this could be linked to limited access to educational facilities. In fact, of the few education institutions available for the community, are located outside Dunga village and are known to be lacking on standard education facilities with inadequate structural facilities for conducive learning environment. This has disadvantaged Dunga community from accessing decent education. The huge distance covered between available schools to Dunga community was seen to hinder access to education for majority of the children. Though school records show high admission numbers of children since the introduction of free education, the turn up rates were significantly low with a huge numbers of school dropouts been recorded over the years. From the respondents who participated in this study, only 32% had access to some kind of formal education, of who majority were immigrants working for local Non-governmental organizations, government institutions outside Dunga village, or were students at the time the study took place. To understand why classroom turn up was significantly low, the study established that majority of the school going children had responsibilities in fish production process, whereas others were engaged in various house hold chores. Little attention and emphasis by the caregivers and the community in general was given to the importance of accessing education. The needs for community's survival outweighed the need to access education making it seem a luxury for most community members who would not afford to educate their children. This can be linked to the community's failure to initiate alternative means of livelihood to counter reduced economic activities since the introduction of water hyacinth in the lake.

3.4 Poverty and Unemployment

More often than not, a close relationship exists between the level of literacy of a community and poverty index of the community. Though Dunga has a relatively small population compared to other regions in Kisumu, the number of economic activities and related opportunities for livelihood are minimal. Evidently, little attention by the national and local government to Dunga community can be attributed to its underdevelopment. Some of the key indicators of underdevelopment in Dunga include limited investment opportunities, limited social amenities and poor infrastructure available for the community. The inequitable distribution of resources has also played a significant role in impoverishment of Dunga community. Limited economic opportunities have left the community to depend on the lake as their major source of livelihood. While the proliferation of water hyacinth in the lake continues to aggravate the situation with reduced economic activity in the lake region. This has led to change in behaviour of local community as members of the community struggle to cope with distressed economic opportunities. Social vices such as prostitution among women, alcoholism and substance abuse among young adults have been recorded to be on the increase. In a region where crime was very rare, trends show increased cases of petty crimes with theft top on the list. Such behaviour changes have both direct and indirect effects to the wellness of the community and overall management/conservation of the lake ecosystem.

Sources of livelihoods for Dunga community as the study found out are fishing, small scale farming, weaving, employment from local NGOs and government institution operating in the area. A number of small scale enterprises such as shops and related retail outlets are present in the area to supply the local population with basic commodities and services. A small number of Dunga's population depended on formal employment from manufacturing industries, non-for profit organizations and government bodies operating around the lake region, whereas a minority practise different forms of farming for subsistence use.

3.5 Economic Activities Common among Ndunga Community

Commonly known as a fishing community, Dunga's economy largely revolves around fishing as the main driver of economy, with fish been used for trade and for subsistence use. According to the study results, 26% of the respondents were dominantly involved with commercial fishing while significant majority of those who said to be in other types of businesses, 18%, partially practised fishing related activities as either fishmongers or fish transporters. In fact, even for the 6% who practised farming, 12% who practised crafting or depended on employment as their main economic activity, depend on fish for their nutritional value as their main source of protein.

Respondents who said to be in business were either small business enterprise owners supplying general goods and services to the local population while others were in tourism business as boat riders or crafting/weaving industry. Of the 12% respondents who practised weaving/crafty majority are women and youths, who depend on the readily available raw material for making their products. Water hyacinth takes lead as their main source of raw material, among other plants found in the lake and neighbouring wetland. The study also found out that unemployment is significantly high with 19% of the respondents not engaged in any regular source of income, which explains the increasing behaviour changes among youths. However, interesting analysis of the community show that the entire population somehow depended on the lake directly for their livelihood and likewise impact on the lake's ecosystem.

3.6 Social, Economic and Environmental Impacts of Water Hyacinth Proliferation in Ndunga.

The dependence of the community on the lake and its resources as source of livelihood, as established by the study, indicates that approximately everybody living within Ndunga village has either been positively and/or negatively affected by water hyacinth invasion of the lake. Thus making it important for the study to assess and analyse how water hyacinth affects the livelihood of the community along their social and economic activities. The study found out that majority of respondents 54%, who participated in the study were not aware of the source of hyacinth in the lake, and only a few , 16%, held the opinion that hyacinth was introduced by foreigners in the lake, with others 30% thought that it was brought by water currents from the Ugandan side of the lake. It is thus not clear as to the origin of water hyacinth in Lake Victoria, though all respondents acknowledged been aware of its presence in the lake for the past couple years and its destructive characteristic.

Fig. 2 Below shows how respondents thought water hyacinth has affected their livelihoods.

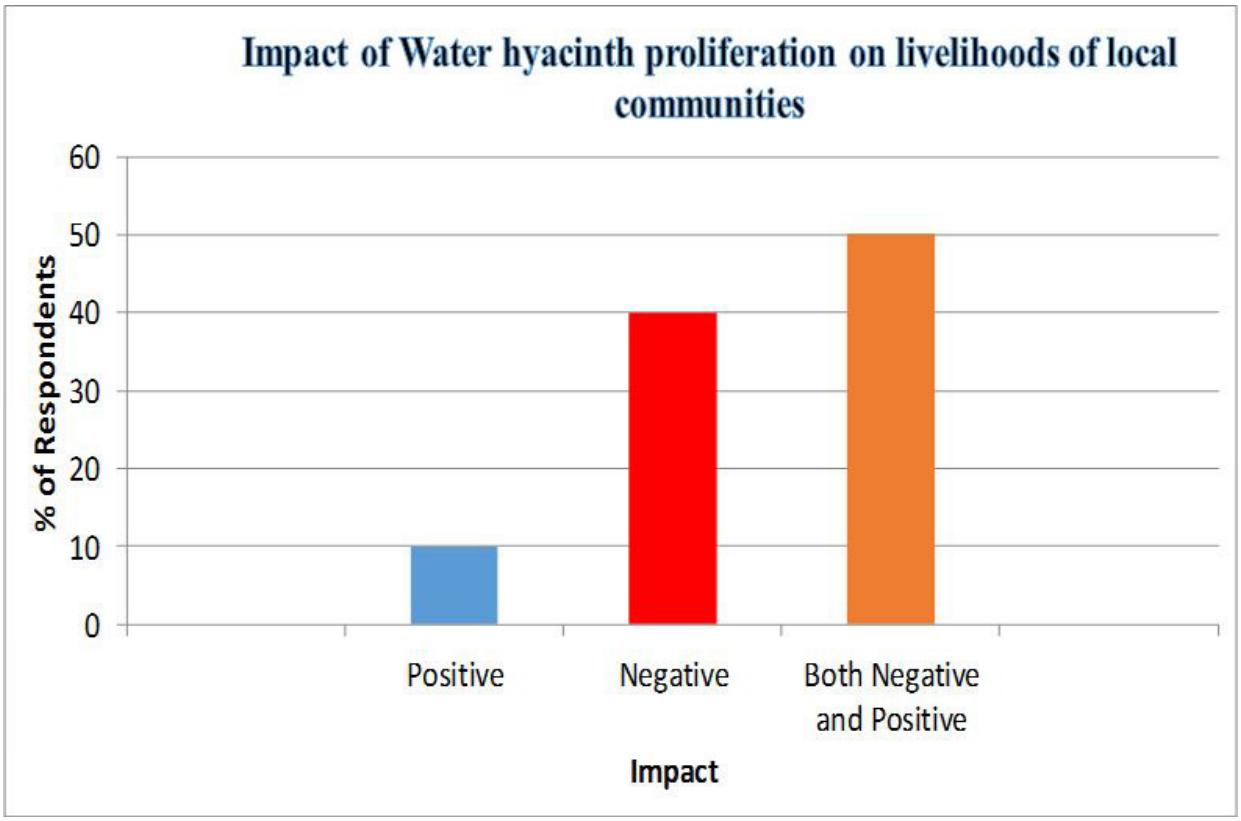

Figure 2: Impacts of Water Hyacinth on the Livelihoods of Ndunga Community

Highlighted in yellow indicate respondents, 26% have been exclusively affected by water hyacinth invasion of the lake negatively, while highlighted in blue,10%, show the percentage of respondents who thought water hyacinth was a blessing in disguise as it had positively affected their livelihoods. However, majority of the respondents, 64%, felt that introduction of water hyacinth in the lake had affected their livelihoods both positively and negatively. Irrespective of the negative impacts associated with water hyacinth invasion of the lake, this indicates that some community members had identified value in the weed for economic gain or otherwise.

3.7 Positive Impacts

First and foremost majority of the youth felt that water hyacinth had increased employment opportunities as they were occasionally hired to remove the weed. Through continuous efforts by various stakeholders to eradicate the weed, many youths had benefited from short term casual employment opportunities to physically remove the weed from the shores of the lake. However, these efforts are not sustainable as the rate of reproduction and spread of water hyacinth in the lake tend to outdo such removal measures. Though hyacinth is viewed as a threat to a significant number of community members that depended on the lake, a portion of the society make an income out of it and are likely to re-introduce the weed in the lake.

The continued loss of traditional methods of livelihoods of Ndunga community from water hyacinth proliferation in the lake has led to the introduction of innovative alternative means of

livelihoods. Among these initiatives include introduction of new products from water hyacinth for income generation from sale of items made using water hyacinth. Some of these items include; furniture items, mats, cards among others. The introduction of new products from the hyacinth has created increased entrepreneurship opportunities for the community through product development, marketing, sales resulting to improved livelihoods. Among those who have largely benefited from this venture are women and youth.

Water hyacinth has boosted weaving business. The use of reeds for weaving of fish baskets among other items was among other traditional social economic activities practiced by women in the society. Identification of water hyacinth as an alternative source of raw material for weaving has led to increased business cautioning the community from reducing traditional raw material as a result of increased harvesting.

Among the livestock keeping community members, water hyacinth is seen as animal feed during dry periods. Though known as a fishing community, a number of community members in Ndunga and its surrounding have kept livestock to boost their means of household income. Majority of animals kept are goats as they are less tedious to handle, require little feeding and easily adapt to unfavorable environmental conditions. Though the lakeside is characterized by humid climatic conditions, vegetation growth in the region is minimal due to the rocky soils. As evidently acknowledged, harvesting of hyacinth for animal feed is a common practice among villagers who keep animals. Hence water hyacinth has been use as feed for animals.

Whereas some farmers use water hyacinth as feed for their animals, others use it for mulching and to make compost manure for their farms. Among respondents who practiced small scale subsistence farming, they acknowledged using hyacinth to make compost manure to nourish their soils with some using it for mulching.

3.8 Negative Impacts

Majority of the respondents indicated that pollution of lake water lists high among other negative impacts water hyacinth has caused to the community. This can be attributed to the significant role the lake has on Dunga community as a source of water for household use, for consumption as well as industrial use. Excessive growth of water hyacinth in the lake brings about eutrophication of lake water making it less suitable for use especially for domestic purposes. This further complicates the social roles given to women and young girls who have to travel long distances to access and fetch water from sections of the lake that seem easily accessible and where water appears cleaner. The study also established that proliferation of water hyacinth in the lake is also significantly attributed to community activities along the lakeshores that lead to pollution of the lake through influx of nutrients in the lake, a condition that creates conducive environment for hyacinth rapid growth.

Reduced fish stock over time recorded second from water pollution as a negative impact of water hyacinth proliferation in the lake. This is as a result of decreased fishing grounds, polluted waters making it unfit for fish consumption, and blocked water ways making movement in water a challenge. Majority of those who indicated reduced fish stock were fishermen due to the nature of their work. They further pointed out that water hyacinth had led to destruction of their fishing nets raising the cost of doing business with increased investment on fishing nets.

Water hyacinth in the lake creates conducive bleeding for mosquitoes and other parasites. This has been evidenced by increased incidents of malaria and bilharzia diseases been recorded in local

medical facilities over the years since the introduction of hyacinth in the lake. Similarly, increased mortality of under 5years old children from these parasitic diseases have been recorded. Though listed as the least, at 4%, negative impact water hyacinth has brought to the community,majority of those affected are children, and their families have had to incur additional costs to access medical treatment.

In an underdeveloped community like Ndunga Village, where no appropriate water supply means are present, children and women suffer the burden of fetching water for the household. In Ndunga for example, children continue to play the huge responsibility of fetching water and firewood. The search for water for household use brings with it significant challenges for children, among them being exposure to disease causing organisms, drowning in the lake, and limited study time for school going children.

Other negative impacts brought about by water hyacinth are reduced activities in the lake such as recreation activities like swimming, sports like boat racing, and local tourism as a vibrant economic activity for some members of Ndunga community had also been hard hit by water hyacinth invasion of the lake.

A significant relationship between the proliferation of water hyacinth in the lake and the increased cost of fishing which has affected local fishermen and fish consumers who now have to dig deeper into the pocket to pay for the increased cost of production. This has directly and indirectly influenced the behavior of some community members as they seek to cope with the increasing cost of survival. Cases of young women engaging in prostitution in exchange of fish to feed their families have been reported to be on the rise. Petty crimes such as robbery by young men have also been reported to be on the increase. Intake of illicit brews and related substance abuse by vulnerably idle men, women and youths is evidently present within Dunga community.

3.9 Impacts on the Environment

As established by the study, there are a number of impacts on the environment and to the lake's ecosystem that are linked to water hyacinth. Among them are;

Physical Impacts- Since its introduction in the lake, according to the community, the volume of water in the lake has continued to reduce significantly and this is characterised by increasing size of the shorelines, as well as decreased water access points especially during periods of intense cover of the lake water by the hyacinth. Other physical changes to the lake water as highlighted by the respondents include change in water colour due to eutrophication, reduction of water temperatures as a result of blocked sun rays from reaching water surface, blocked water ways leading to reduced water movement through currents, and this has potential to reduce the amount of oxygen diffused in the lake water, reduced accessibility and movement in the lake.

Biological Impacts- Though plants are known to be important medium for oxygen-carbon dioxide exchange in aquatic ecosystems, the presence of high mass of water hyacinth in the lake is likely to result in the significant reduction of dissolved oxygen in the water, thus affecting the ability of the lake to support the life of delicate living organisms such as fish. Reduction in dissolved oxygen in the lake can also arise from decomposition of dead organic matter of the hyacinth in the lake due to aerobic processes of decomposition. This alongside increased turbidity of the lake water resulting to reduced oxygen ion exchange in the lake can be attributed to reduced population of certain species of living organisms in the lake. This further alters the food chain, and livelihood

of communities that depend on the lake for as a source of food. As such, the study established that water hyacinth plays a significant role in the biological oxygen deficiency of the lake water and thus affects life of aquatic organisms in the lake.

Chemical Impacts- Unmanaged disposal of water hyacinth, from physically removed in the lake, on the land surface is of concern to the community according to the study respondents. This is because of the foul smell caused by the decaying hyacinth resulting to irritation and discomfort to the local population. During decomposition of water hyacinth, various chemical reactions are likely to take place with exposure to sunlight resulting to the release of methane into the atmosphere.

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O.\ CH_3COOH \rightarrow CH_4 + CO_2. \qquad (1)$$

Since methane is a known significant greenhouse gas, the study determined that continued release of methane to the atmosphere through such processes is likely to contribute to climate change.

Well known for its ability to absorb metal components from the water, disposal of harvested water hyacinth on the land surface is likely to contribute to the transfer and release of heavy and trace metals and related nutrients on lands surfaces which could result to further leaching of the respective metals and nutrients to ground water.

Whether introduction of water hyacinth has affected the negatively or positive, the use of water hyacinth

Whereas water hyacinth invasion of the lake has generated huge attention over its negative impacts, the study went ahead to determine how the community is coping, both at individual and institutional level. As the study found out, a number of localised institutional and community led interventions have been put in place to control the spread of water hyacinth whereas other to caution the local population from the negative effects of water hyacinth proliferation in the lake.

3.10 Bio-Energy production using Water Hyacinth

Recent studies indicate that water hyacinth holds significant potential as a feedstock for biogas production. The continued presence of water hyacinth in Lake Victoria holds a strong promise in the production of localized renewable clean energy for Ndunga community to complement the current conventional non-renewable energy sources for cooking and lighting. Hence, it is important to understand the viability and sustainability of this technology. As such the study focused on availability of raw materials, energy gaps of Ndunga community, community perception in regards to adoption of the new technology, and disposal of slurry residual generated from the biogas digester vis a vis its impact to the environment.

3.11 Availability of raw material

To assess the availability of raw material for biogas production, the study seek to find out the factors and dynamics in play for continued presence of water hyacinth in the lake. Studies show that a combination of anthropogenic and natural factors influence the presence of hyacinth in the lake. Continued pollution of the lake through discharge of waste water, raw sewage, industrial effluents,

nutrient leaching/run off from agriculture farms from the various human activities around the lake create conducive environment for water hyacinth to thrive and reproduce. The warm tropic-equatorial climatic conditions present around the lake's ecosystem present favourable climatic condition for water hyacinth growth.

3.12 Energy needs of Ndunga community

Even as the potential of biogas production from water hyacinth is determined, it was important for the study to establish if a positive correlation between potential bio-energy production and community energy needs exist. As such, the study went further to assess the energy needs of Dunga community through profiling current energy sources and related costs, as well as identifying challenges relating to the current energy sources. Community attitude as regards to technological development play a significant role in its acceptance and adoption. Hence the study seek to gather community's views as regards to this technology.

3.13 Current Energy Sources and associated challenges

As a rural area, many households depend on firewood for their cooking energy needs and paraffin for lighting. In some households, young girls are mandated to fetch firewood for the family, thus spending much of their time gathering firewood at the expense of their study time. Whereas in others, they fetch firewood from the bamboo forest located on the shores of the lake. This activity has led to clearing of the bamboo forest, and poses a great hazard to locals who have to fetch firewood from inside the lake.

As such, generation in biogas from water hyacinth, a product freely available, poses great potential in addressing some of these challenges the community face as it will;

- Bring an alternative solution to energy source. Provide better means of managing the noxious weed and lake in general.
- Provide alternative incentive for community management of the lake.
- Improve livelihoods for communities living around the lake region.
- Boost ecotourism as visitors come to see how the new technology is being used hence opening up the area for development.
- Create more time for children to focus on their studies.
- Help conservation of bamboo woodlots and wetlands around the lakes, hence improved environment.
- Lead to increased harvesting of water hyacinth as well as contribute to clean energy production and reduced carbon emissions from current energy sources (localization of clean energy).

3.14 Water Hyacinth as a Bio-fertilizer

For any technology to be accepted as a viable technology, it not only has to seem beneficial to the community but also prove to be environmentally friendly, for sustainability purposes. The growing

demand for sustainable agricultural practices, has given space to products innovation including application of bio-fertilizers. Bio-fertilizer is known to be a sustainable source of plant nutrients due to its ability to slow nutrient release from the soils whereas improving the soil structure. Digested biomass waste from biogas digesters, otherwise referred to as slurry can be collected for direct application into the farms. From laboratory analysis of data acquired, the concentration of identified minerals is as presented in the table below.

Mineral	Water Hyacinth Samples Concentration (ppm)			
	Samples 1.	Samples 2.	Samples 3.	S.D
Iron	2560	2553	2558	3.6056
Copper	21	21	18	1.7321
Manganese	222.5	221.3	222.2	0.6245
Calcium	1806	1810	1808	1.1547
Phosphorous	795	786.9	791.1	2.3115
Potassium	46060	46054	46066	3
Sodium	3807	3770	3775	2.6457
Magnesium	3110	3111	3121	1.5275

Table 1: Concentration of Minerals in Water Hyacinth Slurry

The table shows results for three samples tested, derived average and a standard deviation (SD) analysis of the results to estimate the concentration for each mineral component. Minerals tested include ions of Iron, Copper, Zinc, Magnesium, Manganese, Calcium, Phosphorous and Potassium. The study established that slurry collected as residue from the process of biogas generation from hyacinth biomass can be applied to the farms. However, the study further found out that slurry from digested mixture of water hyacinth biomass and cow dung is high in nutrient content compared to that of purely digested water hyacinth biomass.

The study also established that water hyacinth can be utilized for the generation of biogas for heating as well as bio-methane which can be utilized for generation of electricity. Though production of biogas from water hyacinth falls slightly lower than the production of biogas from cow dung, it's however preferred for this community setting due to the abundant availability of water hyacinth from the lake.

3.15 Community Perception with regards to the new technology

Asked whether they thought production of bio-energy from water hyacinth would benefit the community positively, 90 % of the respondents agreed with enthusiasm noting that such a technology had potential to;

- Bring an alternative solution to current erratic energy sources.
- Provide better means of managing the noxious weed in the lake through increased harvesting of water hyacinth as a raw material in the production of biogas.
- Provide alternative incentive for community management of the lake

- Improve the livelihoods for the community by raising their living standards
- Boost ecotourism as visitors are likely to come to see how the new technology is been used. Hence opening up the area to development opportunities.
- More time for children to focus on their studies, with reduced amount of time spent fetching firewood.
- Conservation of bamboo woodlots and wetlands around the lakes, hence improved environment.
- Ultimately the technology will lead to increased harvesting of water hyacinth
- Respondents with technical knowledge appreciated the potential contribution to clean energy production and reduced carbon emissions from current energy sources (localization of clean energy production).

4. Conclusion and recommendations

Investigation into the possibility of utilizing water hyacinth to yield biogas adds value to the seemingly noxious weed and solves the problem of water hyacinth management as well as bridging the gap in energy needs of rural communities living around fresh water ecosystems infested by the hyacinth. Promotion of such technological development leads to significant reduction in dependence of non-renewable energy sources such as wood fuel and paraffin; hence an innovative technology in the reduction of greenhouse gas emissions. Besides the potential for energy production, other valuable bi-products, such as high quality bio-fertilizer are obtained from the water hyacinth digestate which has potential to minimize over reliance on expensive mineral fertilizer. Recognizing continued presence of all the factors that influence proliferation of water hyacinth in the lake, and continued challenges in its control, the option of biogas production as a way of energy exploration using water hyacinth could not only sustain local energy production but also improves environmental sustainability promoting the social and economic wellbeing of Ndunga community, and other communities around the world living within ecosystems infested by water hyacinth.

In conclusion, the study recommended the need for further analysis on emerging plants taking dominance in fresh water ecosystems, such as hippo grass, to complement the usage of water hyacinth as bio-energy producers.

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