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Up Scaling Invasive Plant Biomass Briquette Production: Case of Kendu Bay, Lake Victoria, Kenya

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ABSTRACT

Simple, production processes involving local community labour provide useful cottage fuel products. Such conversion of waste or intrusive bio mass to fuel briquettes is more about know-how than large capital infrastructure and funding. This paper describes up scaling a pilot process that converted water hyacinth to briquettes by hands on training of Kendu Beach Community Unit members, in situ, over a two week period. System and target knowledge, before training, and transformational knowledge, post training, were elicited and the results analyzed. Briquettes produced from five plant bio mass types and their respective blends vide carbonization, were tested in a laboratory. Water hyacinth briquettes produced during up scaling were much better than those produced during the pilot production due to machine compaction refinements. Blending five dried biomass types with each other before carbonization yielded higher calorific values despite the labour intensive and relatively low technology mediated process. User acceptance tests were conducted on site. The uptake of the easy to follow; labour intensive process using simple briquetting machines was a success with the community producing briquettes on their own after an initial three day, post drying production run. Such cottage solutions for domestic consumption and sale should be promoted as a sustainable substitute for fossil or wood based fuel. Confidence building measures between the community and their devolved representatives such as ward administrators and members of Constituent Assemblies under the 2012 Constitutional dispensation should be undertaken. The East African Community project LVEMP-II should, through greater stakeholder engagement, have a greater impact on Lake Victoria's ecosystem in order to enhance the livelihoods of the beach communities.

Keywords: **biomass, briquette, up scaling, community, training, cottage production**

INTRODUCTION

Resource use and Energy

Interventions to challenges posed by resource depletion require not only financial, technical or institutional support systems but also social and cultural ones for efficient resource use. Poverty appears to dominate countries on the African continent. Yet such countries while contributing relatively little to total green house gases, and Kenya is no exception, bear a large burden of the impact from the emissions with limited capacity to adapt [20]. Moreover their natural resources are in great demand from countries such as China and India. Thus the negative impacts of climate change are felt disproportionately by the poor and poor countries due to their high dependency on natural resources and limited capacity to adapt.

Access to and control over the resources needed for adaptation varies within countries, communities and even households. It is influenced by external factors such as policies, institutions and power structures. Effective adaptation evolves in an innovation system which represents a significant change from conventional research and development. It is based on an interactive learning process in which agents interact with one another supported by institutions and organizations that play key roles in bringing new products, new processes and new forms of organizations into social and economic use to enhance adaptation to efficient use of resources [22]. The high failure rate of purely technocratic interventions and the instability of international finance regimes underpin the urgency for further development and implementation of integrated and innovative approaches to resource use in Africa.

The global consumption of resources is spiraling upwards. In 1900, for instance UNEP [21] estimated it to be 6 billion tones. It increased to 49 billion tones in 2000 and is estimated at 59 billion tones in 2011. The developed countries lead the pack at 16 tons per person per year while the developing countries use is 4 to 5 tons per person per year which is the recommended level for all of humanity. To achieve recommended consumption level calls for massive investment in technological, financial and social innovation. The use of a holistic solution requires training. Reuse, recyclability, easy to assemble component based machines driven by low energy options need to be developed locally [20].

Several governments and private companies, the world over, are investing in renewable energy. In 2009 total investment in renewable energy exceeded coal energy and now exceeds investments in nuclear energy. Resource efficient technologies for key services such as water supplies, transport, waste recycling and food production are about know-how and not just about capital infrastructure and funding. Strategies to build resilience of community systems are required. This not only requires investment in traditional knowledge producers such as universities but also in cottage industries where community labour for production is not overlooked in the quest for profitability via scalable technology and automation. Thus practical solutions that use community labour to convert waste or invasive [15] species biomass to briquettes as a substitute for fossil or wood based fuel using minimalist technology should be encouraged as an alternative. The attractions of mega government projects must be balanced with realism and modesty so as to mitigate against outcomes that are skewed in their impact on the marginalized many as opposed to the relatively privileged few [19].

Traditionally, energy in the form of firewood, twigs charcoal has been the major source of renewable energy for many developing countries [26]. In sub-Saharan countries over reliance on forest wood for charcoal production, firewood and furniture making has resulted in shortage of fuel wood and led to the depletion of over 75% of the total forest cover and an environmental crisis. The decreasing availability of fuel wood, coupled with the rising prices of kerosene and cooking gas in Kenya, draw attention to the need to reconsider alternative sources of energy for domestic and cottage level industrial use in the country. Such energy sources should be renewable and be accessible to the poor. Thus a transition to a sustainable energy system is urgently needed in the developing countries such as Kenya [2, 24].

Wood fuel is the largest form of energy consumed in the Kenya by far, accounting for about 68% of the national total. Petroleum is the next most important accounting for 22% followed by electricity 9%. Only 2% of Kenya's land area is covered by forest, which produce about 45% of the biomass energy resources including wood wastes [6]. The balance is derived from farmlands in the form of woody biomass as well as crop and animal residues. Intrusive biomass [15] can be part of the solution for this renewable energy promotion framework, by providing an alternative to fast declining wood fuels, that are useful in carbon sequestration and reduction of green house gases. Linkages exists between provision of affordable energy and poverty alleviation and developing pro-poor programs in priority areas such as opportunity (both income and capabilities), empowerment and security [4].

Plant biomass briquettes

Three main control mechanisms for preventing the spread of water hyacinth are biological, chemical and physical [8, 9]. Several useful applications for the plant ranging from: making paper, fiber boards for a variety of end use, basket making, briquetting, stock feed [10], pretreatment for polluted water [11, 14], biogas production, to compost manure [10].

Since a water hyacinth infestation is seldom totally eradicated it is a situation that must be continually managed [7, 16], therefore control by utilization remains the only sustainable option of dealing with the weed and any such other invasive species [12]. The increased reliance on imported fossil based fuel and growing total energy costs outlays, make small scale or cottage industry production and promotion of bio-fuels an attractive prospect [13, 17]. With value addition such as briquetting through carbonization or semi decomposition higher energy yielding briquettes can be obtained [1].

The utilization of biomass residues in their natural form as fuel is difficult because of their low bulk density, low heat release and excessive amounts of smoke they generate [23]. One of the ways to improve the thermal value is the application of briquetting technology [25]. Briquetting can be done with a binder. However, without the binder which is more convenient, sophisticated and costly presses and drying equipments are required and may be inaapropriate in a developing country [5]. As observed [3], for the briquetting industry to be successful in less industrialized countries, the equipment should consist of locally designed simple, low-cost machines that are easy to operate. A process where readily available binders are used becomes cost effective with the use of extrusion or piston press machines fabricated locally as in this study.

In 2012/2013 a baseline study [18] was carried out in three zones adjacent to Lake Victoria-Kendu Bay, Kisumu and Homa Bay to assess the awareness of water hyacinth as an alternative energy resource. A significant relationship was established between zones and awareness versus perception of individuals on use of water hyacinth. A pilot production run was then undertaken at Kisumu Beach Resort with a view to up scaling at other sites. The pilot production process experimented with two processes carbonization and semi-decomposition and used briquetting machines with the following features in mind: ease of use, simplicity of design, low maintenance and affordability with a view to fabrication by jua kali artisans. Briquette samples were tested and showed that samples made from woody plants had greater calorific values than those derived from water hyacinth. Wamukoya & Jenkins, [3] nonetheless found that water hyacinth briquettes produced greater heat intensity, were cleaner, more convenient to use and took up smaller space for storage.

In this study we up scaled the process, training twenty Kendu Beach Management Unit (BMU) members in the carbonized briquette making process using not only water hyacinth (*w*) but also various other invasive plants found rooted at the BMU beach head such as cattails/*Typha* *spp/*'odhong' (*c*), papyrus (*p*), reeds (*r*), river bean/ *Sesbania sesban/* 'orindi' (*b*). These invasive species hindered the fishing activities of the beach community who had to launch their boats from nearby beaches free of such vegetation.

In order to gauge the effectiveness of the hands on training a two part questionnaire was administered in stages: the first part to forty members of the BMU community before the hand on production training and the second part to the twenty trained members only.

METHODOLOGY

Description of the site

Based on the pilot production run the criteria to determine the most suitable site for up scaling were: availability of lake shoreline, accessibility by road, adequate open air drying space, presence of out buildings, in-shed storage facility or land to build one, fenced premises, cooperation of beach community members and whether the earlier baseline survey was done or not. Kendu BMU was the chosen site after a reconnaissance mission.

The site's original lakeshore, see Figure 1, at which fishing boats landed, has undergone serious ecological changes over the years due to siltation from a tributary of River Awach. This transformation of the shoreline was further exacerbated by Kendu Bay Pier turning the area bounded by it and the original shoreline to its left into a wetland that encouraged the growth of invasive grasses, reeds, papyrus and river bean trees.

Figure 1: Kendu BMU Site (*Google Maps 2015*).

Plate 1: Clogged shoreline and river outlet channel.

Only a narrow, barely navigable, channel to the lake remains, see Plate 1 clogged by water hyacinth necessitating relocation of the fishing boats landing site to the beach front on the pier's right. The wetland, however, provided considerable and varied biomass for briquette production.

Target community

The BMU had 198 females and 204 males totaling 402 members. It is registered with the Ministry of Fisheries Development with the purpose of management and development of fisheries resources within its area of jurisdiction as described in section 4 of their bye-laws and in accordance with provision of the Fisheries Act Cap 378 and any regulation made there under. The BMU is also registered with the office of the District Gender and Social Development Officer as a self help Group/Project under the name Kendu Beach Fishermen Tilapia Group. To be a member of the BMU, one pays US$ 1 and the BMU has a monthly general assembly at which each member contributes towards a savings pot which is shared out after every five months.

Pre and post training questionnaire

The questionnaire was structured within the context of sustainable beach community engagement and development to assess their perceptions, attitudes and awareness in order to address the challenges of invasive plant biomass that endanger livelihoods and their potential use through briquette production training. Three types of knowledge were elicited from the respondents: systems knowledge (the context and current state), target knowledge (desired sustainable future) and lastly transformational knowledge (actions for bringing about sustainability transitions) post training.

By and large systems knowledge comprised respondent's: demography, household location, bio-data, household income and expenditure patterns, wealth indicators, access to and affordability of domestic energy while target knowledge comprised: awareness and knowledge of water hyacinth potential and attitude towards briquettes derived from water hyacinth which constituted the first part of the questionnaire. The second part administered after the hands on training provided transformational knowledge: innovation and marketing, culture and practice, knowledge management, the possible environmental impact and feedback on training.

The Kendu BMU comprised of 270 members. The BMU committee was requested to nominate 40 members (15%) to whom questionnaires would be administered. Of this 40 one half (20) would be trained with females and youth constituting at least a third. The sampling was purposive. A few more five (5) in number audited the training unofficially.

Production process

The onsite production process also provided hands on training for twenty BMU members including six women and one physically challenged person, and involved a number of stages: harvesting of materials, drying of the harvested materials (two to three weeks), chopping, grinding where necessary, carbonization, and briquette making using the carbonized char mixed with a binder similar to the process documented in [18]. The twenty participants were divided into three groups of five (5) each plus one or two additional observers per group. Each of the groups was trained by one main trainer and his deputy. They were taken through the process below and supervised throughout the first production run. Thereafter they continued without supervision once they internalized the process within their group with the person who learnt fast becoming the group leader in production. Some of the harvesting and drying was planned three weeks before the actual hands on training commenced so that dried biomass could be available. After the bio mass had dried it took one to two days to make the briquettes starting with the carbonization stage.

The carbonization process is illustrated in Plates 2 to 5. Part of the dried materials were stuffed in a specially modified drum and then carbonized. Modifications on the metallic drum were as follows: four rectangular areas were cut out from the bottom and the top was also cut out in square form for stuffing and a well fitting lid made. The four holes were blocked with a lighting material (dry grass or any other easily ignited biomass material) then placed on three small stones. A cylindrical log was then held vertically in the middle of the drum and then the drum stuffed up to two thirds full only with the dried biomass or blends thereof. When full the log is slowly pulled out as it is rotated. A vent thus results in the middle of the stuffed drum. The drum is then lit from below and allowed to fire up. The smoke coming out changes color from white to blue then red flames emerge. At this point the drum is carefully removed from the stones and sealed at the top using the lid and soil and also around the bottom with soil so as to create an air tight enclosure. After 30 minutes the drum is opened up and material in it found to have been charred. It is poured onto a wheelbarrow and allowed to cool. It is important at this stage to ensure the charred remains do not reignite as this would turn the carbonized material into ash in the presence of air. This procedure is repeated until all the materials have been carbonized and stored ready for briquetting.

Plate 2: a) Drum placed on 3 stone stove. b) Dry material inserted around log.

Plate 3: a) Distribute material evenly around centered log, b) Ignite base.

Plate 4: a) Moisture expelled upon ignition. b) Combustion with clear flame.

Plate 5: a) Drum removed from stove. b) Sealed to burn anerobically.

Plate 6: Carbonized Material.

After carbonization the resulting char, if brittle, was crushed in a bag and if hard put through a manual grinder. The resulting carbonized residue is mixed with a binder material in this case porridge made from poisonous cassava. The porridge was prepared by placing a cooking pot on fire lit by using some of the dry harvested materials. One kilogram of flour was poured into about 8 litres of room temperature water in a separate container and mixed properly before pouring the mixture into boiling water. This is then stirred continuously until the mixture comes to a boil. This binding material is then mixed thoroughly with 10 kgs of carbonized dust until the right consistency of the blended matter is reached. This is determined by squeezing to see if it oozes through the fingers which imply it is too viscous and shaking a hand molded, cigar shaped piece to see if it breaks which implies there is too little binder or not enough water [18]. The consistent mixture was then fed into any of the three manual machines for briquetting. The damp briquettes produced are handled carefully and dried in the sun during the day and covered in the night for at least four days before they are ready for storage indoors in a well ventilated place see plates 7 and 8.

Plate 7: Damp briquette extrusion.

Plate 8: Briquettes dried on prefabricated beds.

Equipment refinement from the pilot

A shed to house equipment and store briquettes was built. The following materials were used: wheel barrow/ wheel cart, carbonizing drum, grinder, mixing basin, binder material, briquette machines and prefabricated drying beds. The manual briquette piston press used in the pilot production was used, as were two refinements designed and fabricated to increase briquette compaction. Both new machines were manual with one based on an well known extrusion screw design US$ 150 and the other a simple, cheap to fabricate (US$ 50) single user, easy to use and assemble machine is based on a piston press with a rectangular mould producing 2 briquettes per cycle, see figures. 2,3 for the model and design respectively. Both were locally fabricated and improved considerably briquette compaction compared with the piston press machine used in the pilot production run.

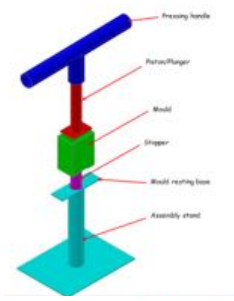

Figure 2: Model of manual piston press.

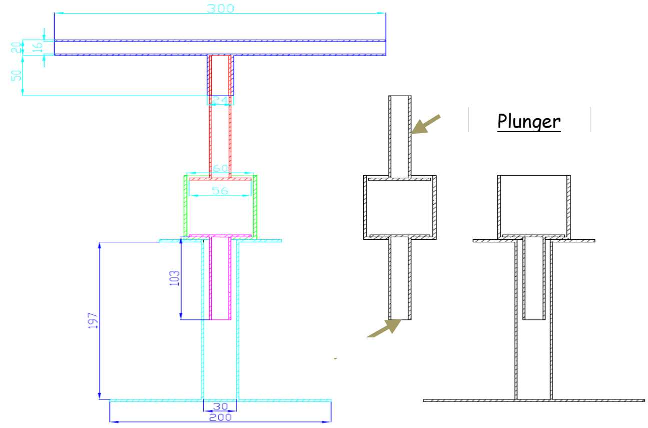

Figure 3: Design of manual piston press: *source Kerich D., KIRDI 2015.*

Types of harvest materials (local and botanical names)

Five different types of materials were harvested. Their names (common, formal, and/or vernacular) and abbreviations are: water hyacinth (*w*), cattails/*Typha spp/*'odhong' (*c*), papyrus (*p*), reeds (*r*), river bean/ *Sesbania sesban/* 'orindi' (*b*). After harvesting these were chopped and then aired out to dry during the day in the open on black polythene bags which were folded over from dusk to dawn as a protection from rain or dew.

Combination of harvested materials

Using the five base dried materials and blending carbonized combinations thereof a variety of briquettes were produced so as to determine their quality. Tests were carried out in the laboratory to determine the calorific value (*cv*), ash (*ac*) and moisture content (*mc*), fixed carbon (*fc*) and volatile matter (*vm*). Sixteen samples were produced and each sample was labeled using the following code: *k(i)*, where *k* denotes the site Kendu and *i= w,c,p,r,b* or any unique unordered combination thereof.

RESULTS AND DISCUSSION

System knowledge

Bio-data

Of the 40 respondents 28 were males and 12 females. Twenty received hands on training 14 males and 6 females including one physically challenged male. The age distribution for the year intervals: < 20; 20-30; 31-40, and >40 was 3, 7, 11 and 19 respectively. Thus females and youth comprised 42.5% and 52.5% respectively of the group trained. The distribution by education levels: primary, secondary and tertiary is 26, 9 and 5 respectively. The location of households was 62.5% near the lake, 32.5% in rural areas and 5% in urban areas with 77% of the respondents living within 5 kms from the lake shore.

Income patterns

The main household sources of income were fishing (38.5%) , self employment (41%) and farming (20.5%) with the monthly household income distributed as follows in Ksh : <15480 (55%), 15481-30960 (35%), 30961-46,440 (5%) and >46,440 (5%) where 1US$ = Ksh 95.4. Of the 28 respondents that fished: 78% sold some, 14.3% ate all while 7.1% sold all the fish caught. This confirms the importance of fishing in the region [7]. Whereas 80% had access to agricultural land only 62.5% owned land. Of those (33) who grew food crops: 63.6% sold some, 33.3% ate all while 3% sold all indicating subsistence nature of farming with the majority having to buy food from the market 97.5% as they were not self sufficient. Thus 82.5% of respondents indicate that there are days when they lack having adequate food.

Wealth indicators

Respondents owned the following: radio (94.9%), television (26.3%), bicycle (42.1%), motorcycle (19.4%) and mobile phone (89.7%). Whereas 40% had access to newspapers only 10% had access to electricity.

Using the Pearson chi- squared test there is a statistically significant association between access to newspapers and gender of the respondent $\chi(1) = 3.339$, $p = 0.050$. Male respondents tend to have greater access to newspapers than their female counterparts.

Wealth indicators vs household monthly income

The chi-square tests for household monthly income versus ownership of radio, television, bicycle and mobile phone respectively show no significant relationship. Thus the mobile phone is not an indicator of wealth these days due to high penetration levels with decreasing cost. However, ownership of motor cycles is an significant indicator of wealth since the corresponding test yielded $\chi(3) = 9.776$, $p = 0.021$.

Household energy sources, usage and expenditure for lighting and cooking, issues

The main sources of household energy for lighting are: kerosene (69.2%), electricity (10.8%) and solar (10%). Of interest is the dominance of fossil-based fuel, the emerging use of solar lamps and relatively low dependence on electricity. For cooking, fossil based fuels dominate with firewood being the highest (80%), followed by charcoal (77.5%), kerosene (37.8%), gas (LPG) (7.9%) and electricity (2.6%). Cooking implements used are predominantly: the 3 stone firewood stove (87.2%), charcoal jiko (75%), followed by kerosene stove (38.9%), microwave oven (5.3%), electric stove (5.1%) and solar oven (5.1%).

The distribution of the monthly expenditure on fuel for cooking is : Ksh 1-1000 (37.5%), Ksh 1001-2000 (22.5%) and Ksh 2001-3000 (40%) respectively. The household distribution of percentage monthly income spent on lighting and cooking is: (1-20)% 70%, (21-40)% 12.5%, (41-60)% 10% and (61-70)% 7.5%. 55% consider expenditure on lighting and cooking to be high, 42.5 % fair and 2.5% low.

As a result 97.4% were interested in a more affordable substitute for household cooking needs and also willing to use their labour to produce such a substitute from commonly occurring waste or invasive plant biomass respectively. The top ranked household energy issues are: affordability (68.5%), accessibility (10.5%), quality (10.5%), quantity (5%) and reliability (5%). Thus affordability is the top ranked issue by far.

Income and Fuel Expenditure Patterns

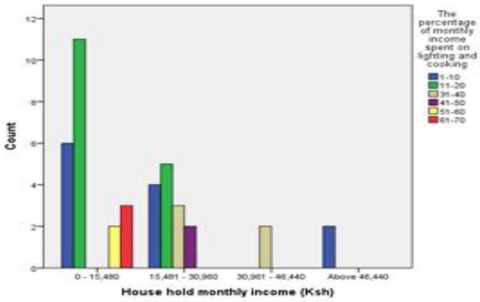

Figure 4: Household monthly income vs % spent on lighting and cooking.

For the cross tabulations in fig.4 there is a statistically significant association using the Pearson chi square test, $\chi(15) = 30.093$, $p = 0.012$, between household monthly income and the percentage of monthly income spent on lighting and cooking.

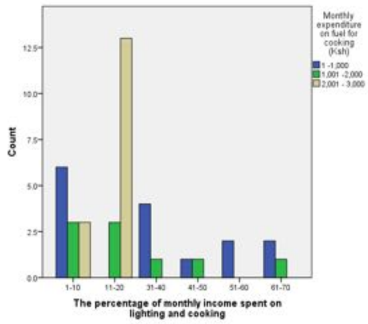

Figure 5: % Household monthly income spent on lighting and cooking vs Monthly expenditure on cooking fuel.

Cross tabulations yield fig.5 for which there is a statistically significant association, $\chi(10) = 25.463$, $p = 0.005$, between the percentage of monthly income spent on lighting and cooking and monthly expenditure on fuel for cooking .

Household energy issues and household monthly income

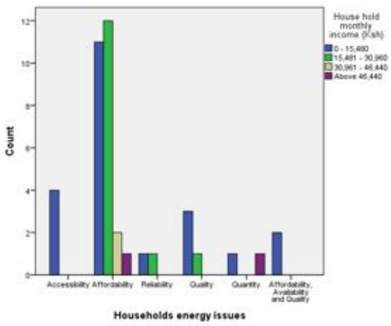

Figure 6: Household energy issues vs Household monthly income.

The chi-square test yields for the cross tabulation in fig.6, $\chi(10) = 6.208$, $p = 0.313$ indicates that there is no statistically significant association between household energy issues and income levels. However, affordability is a major concern to all income groups.

Target knowledge

Awareness

Water hyacinth was perceived by 97.4% as a problem in the area with 27.5%, 42.5% and 30% indicating that the invasive weed covered the local shoreline for periods 1-3, 3-5 and > 5 months respectively thus hampering fishing activities. This affected beach communities (97.5%) most. Institutions that have expressed concern are NGOs (90%), public institutions (5%) and private institutions (5%).

This is an interesting perception since the East African Community (EAC) regional institutions such as the Lake Victoria Basin Commission (LVBC) whose mission [29] is to promote, facilitate and coordinate activities of different actors towards sustainable development and poverty eradication of the Lake Victoria Basin is headquartered in Kisumu. Moreover one of its five activities focus specifically on the environmental management of the Lake, including control and eradication of the water hyacinth weed. At the national level the Ministry of Environment and Mineral Resources of the Government of Kenya is designated the focal point Ministry acting as a link between LVBC and Kenya.

Attitude towards briquettes

Most respondents (71.8%) were aware that water hyacinth could be used to produce a substitute for wood fuels; while (62.5 %) felt that such an alternative would significantly improve the quality of life. Whereas 67.5% had high to very high expectations on the use of water hyacinth as opposed to local wood briquettes only 65% knew what a briquette was. Their opinion on the quality of water hyacinth briquettes as opposed to those made from local wood was: high to very high (60%), moderate (37.5%) and very low (2,5%). Yet the extent of usage of water hyacinth briquettes instead of local wood as fuel would be: high to very high (65%); moderate usage (27.5%), low to very low usage (7.5%) respectively.

The cross tab between normalized monthly household expenditure on cooking fuel and the expectations on the use of water hyacinth as opposed to local wood briquettes are given in fig. 7.

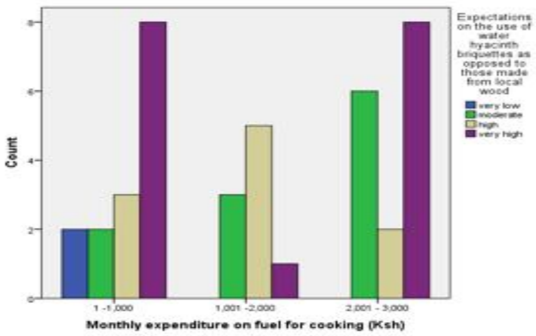

Figure 7: Monthly cooking fuel expenditure vs Expectations on hyacinth viz a viz wood based briquette usage.

The chi-square test on raw data yields $\chi(8) = 17.743$, $p = 0.023$ indicating a statistically significant association, however, when the data is normalized, see fig 7, we obtained $\chi(6) = 12.345$, $p = 0.055$, that is, expectations on the use of water hyacinth briquettes are similar across all monthly expenditure levels on fuel for cooking.

There is a statistically significant association between the location of the household and the extent of usage of water hyacinth briquettes in place of local wood fuels since $\chi(10) = 24.199$, $p = 0.007$; that is those who reside near the lake would be more inclined to use water hyacinth briquettes in place of local wood fuels than those who live further from the lake.

Transformational knowledge

Innovation and Marketing

97.5% of respondents felt it was possible to improve the quality of water hyacinth briquettes: by mixing with other woody plants (60%), experiment with various binders (25%), greater compaction during the press stage (12.5%), and refinement of the carbonization process (2.5%). Whilst the majority 52.5% felt that they would produce sufficient briquettes by increasing production for the market, 40% would sell surplus to neighbors while 7.5% would produce for domestic use only. On how to upscale market production: 42.5% would increase group production size; 32.5% would increase the number of carbonization drums while 25% would invest in more briquette presses. The optimum group production size envisaged was 2 to 4 (25%), 5 (42.5%), and >5 (32.5%) . On how to organize the group: as a registered *chama* (62.5%) and as an informal *chama* (35%). The anticipated pricing for 1 kg of briquettes to local customers the distribution was: Ksh 21-30 (52.5%), Ksh 11-20 (42.5%) and Ksh <10 (5%). The marketing of briquettes would be through local radio (42.5%), informal networks (27.5%), community mobilization (27.5%) and mobile phones (2.5%).

Culture and Practice

Whether cultural/societal restrictions applied in briquette production: no (59%), yes (30.8%) with not sure (10.3%). Sustaining production when water hyacinth migrates away from the beach: 47.4% would harvest residual hyacinth, 42.1% use other invasive plant species, 7.9% use agricultural waste i.e. maize or sorghum stalks and or leaves while only 2.6% would cultivate hyacinth in ponds.

Impact

The impact of converting water hyacinth to briquettes leading to a reduction in its proliferation were considered to be: significant (87.2 %), moderate (7.7%) and little (5%). The impact on the improvement in shoreline quality and aesthetics thus promoting tourism and conservation of the environment respectively was a resounding 100% yes in both cases. On how conservation of the environment would be helped: reducing tree cutting (67.5%), reducing invasive plant species (20%) and reducing fossil-fuel pollution (5%).

Knowledge Management

Spreading the knowledge of briquette making to other beach communities would reduce: the importation of fossil based fuels (94.9%) and foreign exchange used to import such fuels (97.4%). Water hyacinth management locally could be improved by: training members of other BMUs (48.7%), training other BMU members (43.6%), sensitizing ward administrators (5.1%) and lobbying county representatives (MCAs) (2.6%).

Water hyacinth management capability regionally could be improved by: sensitizing constituency MPs (56.4%), lobbying County Governors (38.5%) and lobbying members of the East African Legislative Assembly (5.1%). Here again the EAC is perceived to be too remote from the lake community. This despite the Lake Victoria Environmental Management Project Phase II (LVEMP-II) being an EAC regional initiative coordinated by the LVBC Secretariat. Furthermore LVEMP-II [30] was designed to address major environmental concerns in Lake Victoria Basin (LVB) which had adverse impact on the LVB ecosystem, as well as the region's economy and livelihoods. These include the resurgence of water hyacinth and other invasive weeds and climate change. Under the project's component 1: Strengthening institutional capacity for managing shared water and fisheries resources: one of the major achievements in since 2009 is the development and subsequent implementation of a regional Water Hyacinth Surveillance and Management Strategy for the Lake Victoria Basin.

Training feedback

The trained cohort was 25 or 64.1% of the group. The majority of them were very positive about the training (65.4%) while 34.6% considered it was okay. Whether they enjoyed the hands on training approach: (64%) strongly agreed while (36%) agreed.

Whether they took their time to learn briquetting skills and whether they wished to be informed on new improvements to briquette making technology: strongly agreed (69.2%), agreed (23.1%), disagreed (7.2%) in both cases respectively giving a statistically significant association with $\chi(3) = 17.341$, $p = 0.001$.

A statistically significant association between those who wished to be informed on new improvements to briquette making technology and their level of education since the chi-square test yields $\chi(6) = 13.459$, $p = 0.036$ indicating that the more educated were more interested to learn about new briquetting technologies. Similarly the association between wishing to be informed on new technologies and familiarity with water hyacinth is also statistically significant with the corresponding test indicating $\chi(8) = 12.168$, $p = 0.007$.

Training and opinion on briquette quality

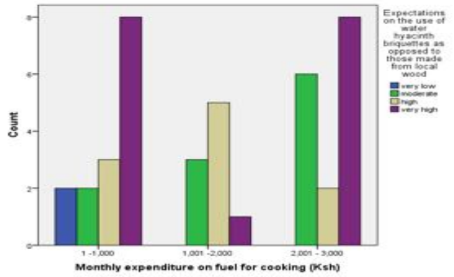

Figure 8: Impact of training vs Opinion on quality of water hyacinth *viz viz* wood based briquettes.

For the fig. 8 cross tab there is a statistically significant association between those trained in briquette making and their opinion on the quality of water hyacinth briquettes for cooking as opposed to those made from local wood, $\chi(3) = 15.45$, $p = 0.001$; that is, those who have undergone training are more knowledgeable about the quality of water hyacinth briquettes as opposed to those made from local wood fuels than those not trained.

Age vs cultural/societal restrictions, enjoyment of training, willingness to be informed

Age appears to be an important demographic factor since we have a statistically significant association with the belief that cultural/societal restrictions may apply to briquette making and marketing $\chi(6) = 14.046$, $p = 0.029$. That is older people see no such restriction while younger ones appear to believe that there are probably because they are not as thoroughly aware of cultural issues. The association of age and the enjoyment of hands on training on the one hand and age and the willingness to be informed of new briquetting technologies on the other hand are both statistically significant with the chi-square tests yielding $\chi(3) = 11.545$, p = 0.009 and $\chi(8) = 17.911$, $p = 0.036$ respectively.

User Acceptance tests

Three simple tests were carried to demonstrate to participants the efficiency of the fuel produced after drying thoroughly. These were the ignition test (IT), water boiling test (WBT) and the cooking test (CT). In the IT 1.5 kg of briquettes were placed in a *jiko,* lit using dried papyrus heads, and the time taken for the briquettes to glow red was measured. The WBT was the time it took to bring 1 litre of lake water to a boil using 1.5 Kg of briquettes in a *jiko* and the time to bring the water to boil (once bubbles rose from the bottom of the water in the pot and burst at the surface) recorded.

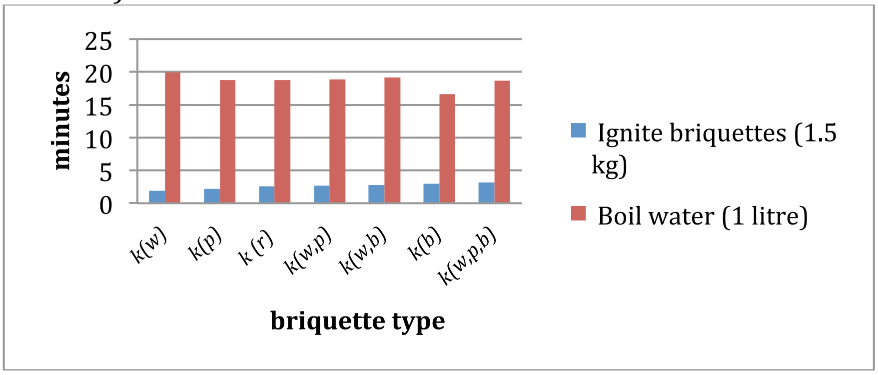

Figure 9: Jiko Test: Time to ignite briquettes (1.5 kg) and Boil water (1 litre).

From fig. 9 we note that briquettes made of water hyacinth *k(w)* took the shortest time (1.85 minutes) to ignite while *k(w,p,b)* briquettes from the combination of water hyacinth, papyrus and river bean respectively took the longest time to ignite (3.13 minutes). To bring 1 litre of water to its boiling point; *k(b)* took 16.60 minutes , the shortest , whereas *k(w)* took 19.98 minutes, the longest. It appears that *k(b)* briquettes have more fixed carbon and greater calorific value since it boiled water in the shortest time while k(w) has higher volatile matter making it ignite faster than the other samples tested.

To demonstrate the cooking value of the briquettes a meal popular locally was prepared for twenty participants. It consisted of deep fried then stewed nile perch (2 Kg. deep fried then stewed), fried kales (1 kg) and maize meal bread (2 Kg. *ugali*). Additional ingredients for the stew were onions (0.5Kg), tomatoes (1Kg), cooking oil (3 litres), salt (0.25 Kg)., and water (10 litres). The total cost was Ksh 1655 or US$ 18.5. Frying the fish and kales took 52 and 20 minutes respectively. Cooking the *ugali* using 3 litres of boiling water took 46 minutes. Two jikos and three replenishments of briquettes, about 1.5 kg each, used for each stove; fanning regularly to improve incandescence of the briquettes and shaking the grey ash resulting from burnt briquettes that blocked the stove vents occasionally to sustain burning.

Briquette quality

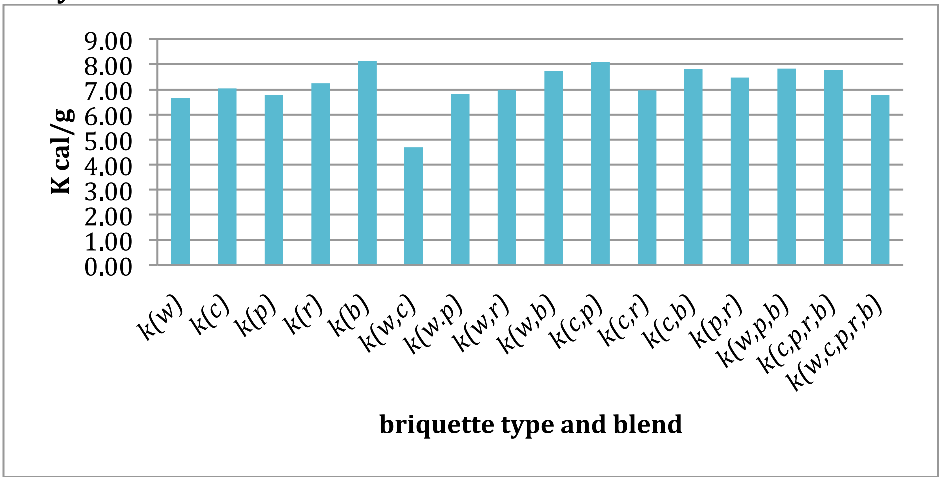

Figure 10: Calorific value (*cv*) of briquettes based on five biomass types and blends

The calorific value or heat value is the most important fuel property which determines the energy content of a fuel. For the samples in fig. 10 the average *cv* is 7.18 K cal/g see table 2. For the five biomass types the *cv* ranges from (6.65 K cal/g) *k(w),* the lowest, to (8.15 Kcal/g) *k(b),* the highest, as river bean is more woody than water hyacinth. The *cv* for the other three biomass types lies within this range. Thus blending dried water hyacinth with various other dried biomass types for carbonization should help improve the *cv* of the resulting briquettes. This is so for all the blends in fig 5 except *k(w,c)* where *cv* is 4.70 K cal/g, clearly an outlier, perhaps due to incorrect blended proportions of dried water hyacinth and cattails at carbonization and high ash content.

Moisture content (*mc)* is a property that can affect the burning characteristics of biomass fuel and ranges see table 1 from (3.53%) *k(w,p)* to (10.22%) *k(w,p,b)* which is an acceptable range [25,28]. Ideally lower *mc* should imply higher *cv.* The data in table 1does not support this since the training production 'rule of thumb measures' may not have been complied with strictly.
Ash content (*ac*) is the non combustible component of bio mass and has significant influence on the heat transfer to the surface of the fuel*.* The *ac* ranged, see table1, from (21.81%) for *k(c,r)* to (67.90%) for *k(w,p)* the latter clearly an outlier perhaps due to sand seeping into the carbonized process when covering the top with sand see plate 5b. Some studies [27] report that the higher the ash content the lower the calorific value. The data in table 1, however, due to the very basic production process does not conform to this trend.

Volatile matter (*vm*) represents the components of carbon, hydrogen and oxygen present that when heated turn to vapour. It has been shown to influence the thermal behavior of solid fuels [27]. It ranged from (24.52%) for *k(c,r) to* (53.47%) for *k(c,b)* table1*.*
Fixed carbon (*fc*) of a fuel is the carbon available for combustion and is the residue in the laboratory tests determined by the equation:

$$\% fc = 100 - (\%ac + \%mc + \%vm)$$

Table 1: Carbonized biomass types and blends: fuel properties of briquettes.

No	Biomass type and blend	Briquette Type	Moisture content	Volatile matter	Ash content	Fixed carbon	Calorific value K cal/g
1	Water Hyacinth	*k(w)*	4.69%	34.63%	47.20%	13.48%	6.65
2	Cattails	*k(c)*	3.67%	25.37%	59.21%	11.75%	7.05
3	Papyrus	*k(p)*	6.16%	38.62%	35.20%	20.02%	6.78
4	Reeds	*k(r)*	3.83%	24.52%	38.97%	32.68%	7.25
5	River Bean	*k(b)*	6.33%	32.72%	39.29%	21.66%	8.15
6	Water Hyacinth and Cattails	*k(w,c)*	3.77%	33.01%	49.54%	13.68%	4.70
7	Water Hyacinth and Papyrus	*k(w.p)*	3.53%	24.66%	67.90%	3.91%	6.81
8	Water Hyacinth and Reeds	*k(w,r)*	7.75%	33.16%	29.61%	29.48%	7.00
9	Water Hyacinth and River Bean	*k(w,b)*	5.27%	30.54%	51.48%	12.71%	7.73
10	Cattails and Papyrus	*k(c,p)*	8.08%	26.65%	23.78%	26.65%	8.08
11	Cattails and Reeds	*k(c,r)*	6.53%	46.39%	21.81%	25.27%	6.96
12	Cattails and River Bean	*k(c,b)*	6.86%	53.47%	24.48%	15.19%	7.80
13	Papyrus and Reeds	*k(p,r)*	8.06%	29.29%	27.38%	35.27%	7.48
14	Hyacinth, Papyrus and River Bean	*k(w,p,b)*	5.72%	28.27%	44.50%	21.51%	7.83
15	Cattails, Papyrus, Reeds and River Bean	*k(c,p,r,b)*	10.22%	30.04%	33.38%	26.36%	7.78
16	Water Hyacinth, Cattails , Papyrus , Reeds and River Bean	*k(w,c,p,r,b)*	9.26%	35.08%	37.06%	18.60%	6.77
		average k	6.23%	32.90%	39.42%	20.51%	7.18
		max k	10.22%	53.47%	67.90%	35.27%	8.15
		min k	3.53%	24.52%	21.81%	3.91%	4.70

It was reported, during the tests, that the briquette samples tested were not homogeneous in the sense that different parts of a briquette sample yielded values that were not necessarily consistent. This seemed to imply that the mixing of the carbonized char with the binder was not necessarily thorough and that the binder mixture itself was not necessarily consistent. Sand inadvertently seeping through the top of the drum when attempting anaerobic combustion could explain higher ash content of some samples. The equal proportion of dried matter to be blended prior to carbonization was not always consistent in measure.

On comparison of the fuel properties between the water hyacinth briquettes produced during earlier 2012 pilot production run [18] and those produced during the up scaling in Kendu Bay we have on average see table 2:

Table 2: Water hyacinth briquette fuel properties: pilot [18] vs upscale production

Properties	Pilot	Upscale
*cv (*K cal/g)	3.70	6.65
mc %	8.28	4.69
vm %	26.03	34.63
ac %	62.92	47.20
fc %	2.78	13.48

It is clear, see table 2 that the quality of briquettes produced during the upscale stage are much better than those produced during the pilot stage since the former had higher *cv*, *vm* and *fc* and lower *mc* and *ac* than the latter respectively. This is due to the refined screw press and piston press machines used that produced greater briquette compaction.

CONCLUSION

The main household sources of income were self employment (41%), fishing (38.5%), and farming (20.5%) and most households (55%) lived on less than US$ 150 per month. The majority (97.5%) had to buy food from the market as they were not self sufficient. A high proportion (85%) lacked having adequate food on some days because they did not have a steady income, with the seasonal movement of water hyacinth to and from nearby beaches exacerbating the income from fishing where applicable. Interestingly the mobile phone is not an indicator of wealth due to high penetration levels (87.5%) and decreasing cost with the sale of pre owned mobiles. Ownership of motor cycles on the other hand is an significant indicator of wealth with the chi-squared test yielding $\chi(3) = 9.776$, $p = 0.021$.

Water hyacinth was perceived by 97.4% as a problem in the area with the invasive weed covering the local shoreline for periods up to 5 months hampering fishing activities and affecting beach communities (97.5%) most. Institutions that have expressed concern are NGOs (90%), private institutions (5%), with public institutions (5%). The latter is an interesting perception since the Lake Victoria Basin Commission (LVBC) an East African Community (EAC) institution is based in Kisumu, with one of its five activities in line with its mission focusing specifically on environmental management of the Lake, including control and eradication of the water hyacinth weed [29]. The perceived impact of a regional institution eighty miles from the site with a focal point Ministry of Environment and Mineral Resources of the Government of Kenya acting as a link between LVBC and Kenya appears to indicate low public sector engagement with such beach communities on this issue.

For cooking, wood and fossil based fuels dominate with firewood being the highest (80%), followed by charcoal (77.5%), kerosene (37.8%), gas (LPG) (7.9%) and electricity (2.6%). Those who reside near the lake would be more inclined to use water hyacinth briquettes in place of local wood fuels than those who live further afar. Thus the domestic consumption of such homemade briquettes was an attractive proposition and (62.5 %) felt that such an alternative would significantly improve the quality of life.

Although there was no statistical association between household energy issues and income levels the major issue across all income levels was affordability. Those trained were not only more knowledgeable about the quality of water hyacinth briquettes as opposed to those made from local wood fuels than those not trained but were also aware through the training that blending dried water hyacinth with other invasive dried plant bio mass added value to briquette quality. Domestic consumption and marketing strategies based on blended plant biomass appeared to have been internalized. The trained cohort also expressed an overwhelming willingness (92.3%) to learn about improvements to the production technology and process.

The anticipated impact of intrusive plant biomass conversion to briquettes on the improvement in shoreline quality and aesthetics thus promoting tourism and conservation of the environment respectively was affirmative (100%) in both cases. Conservation of the environment would be helped by: reduction in tree cutting (67.5%), reduction of invasive plant species (20%) and reduction in fossil-fuel pollution (5%).

Despite devolution in 2012 the confidence held in the representatives closest to the people such as ward administrators and Members of Constituent Assembly together is only (7.7%.). Water hyacinth management capability regionally could be improved by: sensitizing constituency MPs (56.4%), lobbying County Governors (38.5%) and lobbying members of the East African Legislative Assembly (5.1%). The East African Community (EAC) appears remote despite the Lake Victoria Environmental Management Project Phase II (LVEMP-II), designed to address major environmental concerns in Lake Victoria Basin (LVB) that have an adverse impact on its ecosystem as well as the region's economy and livelihoods, being coordinated by the LVBC Secretariat based in Kisumu only 80 kilometers away.

RECOMMENDATION

Community centric solutions that convert waste or invasive biomass to briquettes, using relatively low technology mediated processes should be promoted as a sustainable substitute for wood or fossil based fuel.

Trained beach community members should in turn train members of other Beach Management Units in affected counties to form a lakeside network of BMUs facilitated by private and public institutions, in particular, County Government line item budgets for environment, energy and trade and the Constituency Development Fund for constituencies represented by MPs.

Confidence building measures between the community and their closest representatives such as ward administrators and Members of Constituent Assemblies under the 2012 Constitutional dispensation should be undertaken.

The East African Community's, Lake Victoria Basin Commission LVEMP-II project with its focal point the Ministry of Environment and Mineral Resources of the Government of Kenya, should have a greater impact on the lake's ecosystem in order to enhance the livelihoods of the beach communities through greater stakeholder engagement.

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