UNIVERSITÉ DU QUÉBEC À MONTRÉAL

LE BAMBOU POUR LA PRODUCTION DE BIOÉNERGIE À L'ÎLE MAURICE

MÉMOIRE

PRÉSENTÉ

COMME EXIGENCE PARTIELLE

DE LA MAÎTRISE EN SCIENCES DE L'ENVIRONNEMENT

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DÉDICACE

À tous ceux et celles qui,
de près ou de loin,
contribuent à améliorer
le monde dans lequel
nous vivons.

AVANT-PROPOS

Ce travail de recherche fut réalisé dans le cadre d'un projet intitulé « *Bamboo for bio-energy production in Mauritius.* », et a été dirigé par le professeur Marc Michel Lucotte. Il est présenté sous forme d'un article scientifique rédigé en anglais, précédé par un résumé général, rédigé en français. Suite au dépôt final, l'article sera soumis pour publication dans le journal scientifique l'*International Journal of Forest Engineering.* Le soutien financier provient principalement du Programme canadien de bourses de la francophonie (PCBF), sous la forme d'une bourse d'étude octroyée à l'auteur de cette recherche. Le Département du *Chemical & Environmental Engineering* de l'Université de Maurice (UOM) ainsi que la *Mauritius Sugarcane Industry Research Institute* (MSIRI) ont contribué à la réalisation des analyses en laboratoire décrites dans la méthodologie. De plus, cette recherche n'aurait pas été possible sans la participation de Monsieur Pierre Ludovic et d'*Omnicane Milling Operations Limited* qui nous ont accordé l'autorisation d'échantillonner sur leurs terres, ainsi qu'à tous les participant-e-s ayant répondu aux questionnaires. L'auteur de cette recherche est l'auteur principal de l'article scientifique.

L'auteur principal a planifié le design expérimental, effectué l'échantillonnage des bambous, les analyses en laboratoire en collaboration avec le MSIRI et l'UOM, l'échantillonnage des questionnaires, ainsi que l'analyse des résultats et la rédaction de l'article. Le professeur Charles Séguin a contribué à la planification du design expérimental et l'interprétation des questionnaires. Le professeur Marc Michel Lucotte a grandement contribué et participé à l'élaboration du design expérimental, a effectué la supervision des travaux de terrain et de laboratoire et a contribué à la rédaction, ainsi qu'à la révision du texte.

RÉSUMÉ

Le bambou, reconnu mondialement pour sa croissance rapide et ses divers champs d'application, a acquis une attention accrue au cours de ces dernières décennies. Il est utilisé par des milliers de personnes comme matière première pour la production de biomasse à des fins énergétiques, pour la fabrication de meubles, dans l'industrie agroalimentaire et bien d'autres usages encore. Malgré son abondance à l'île Maurice, cette plante n'est pas toujours valorisée. Ce travail de recherche présente les propriétés physiques et chimiques de deux espèces de bambou – le *Bambusia vulgaris* et le *Bambusia bambos,* comparées à la bagasse de canne à sucre pour des fins énergétiques. Dix échantillons de chaque espèce ont été testés quant à leur pouvoir calorifique supérieur/brut (PCS), leur teneur en humidité, en cendres et en chlorure. Les résultats ont démontré que les deux espèces ont un très bon potentiel énergétique avec un PCS de 16,77 MJ/kg pour le *Bambusia vulgaris* et 17,44 MJ/kg pour le *Bambusia bambos*, et sont des sources fiables de biomasse avec un potentiel de récupération d'énergie de 717, 8 GJ/ha/an et 1587, 1 GJ/ha/an respectivement. Comparativement, le PCS pour la bagasse de canne à sucre était de 18,33 MJ/kg avec un potentiel de récupération d'énergie de 824, 9 GJ/ha/an. En parallèle, une recherche sur l'acceptabilité sociale et la perception des citoyen-ne-s mauricien-ne-s, sur l'utilisation de la biomasse de bambou pour la production de bioénergie comme alternative aux combustibles fossiles, a été menée par l'entremise de questionnaires semi-dirigés. Les questionnaires ont été administrés à un total de 54 répondants, soit 3 hommes et 3 femmes interrogés au hasard dans chacun des 9 districts de l'île. Les résultats ont démontré que les participant-e-s sont conscient-e-s des nombreux enjeux liés à l'exploitation des combustibles fossiles et soutiennent l'utilisation des sources d'énergie renouvelables pour la production de bioénergie. Quatre-vingt pour cent des participant-e-s ont soutenu l'utilisation et l'implantation de la biomasse de bambou pour la production de bioénergie dans le mix énergétique dans l'optique de réduire leur empreinte écologique.

Mots-clés : Bambou, *Bambusia vulgaris, Bambusia bambos*, biomasse, énergie-renouvelable, pouvoir calorifique brut, acceptabilité sociale.

ABSTRACT

Bamboo, globally renowned as being one of the fastest-growing plants in the world with versatile applications, has gained an increasing attention during the past decades. It is being used by millions of people around the globe as a biomass resource for energy production, as well as for timber, furniture making, in the food industry and many more. So far, in the Island of Mauritius, little to no consideration has been given to this fascinating plant. This paper presents the physical and chemical properties of two species of bamboo - *Bambusia vulgaris* and *Bambusia bambos*, compared to sugarcane bagasse for bio-energy production. Ten samples of each species were tested for gross calorific value (GCV), moisture, ash and chloride content. The results show that both species have a very good potential for energy recovery with a GCV of 16.77 MJ/kg for *Bambusia vulgaris* and 17.44 MJ/kg for *Bambusia bambos*, and are valuable sources of biomass with an average energetic yield of 717.8 GJ/ha/yr and 1587.1 GJ/ha/yr respectively. In comparison, the GCV for sugarcane bagasse was found to be 18.33 MJ/kg with an energetic yield of 824.9 GJ/ha/yr. Simultaneously, a research survey on community acceptance and perception of the Mauritian citizens towards the utilisation of bamboo biomass as an alternative to fossil fuels for bio-energy production was conducted via semi-structured questionnaires. The questionnaires were administered to a total of 54 respondents. 3 women and 3 men were randomly interviewed in each of the 9 districts of the island. The results show that the participants are very much aware of the many issues related to the exploitation of fossil fuels and support the use and implementation of renewable sources of energy for bio-energy production. Eighty percent of the participants supported the implementation of bamboo biomass in the overall energy generation mix in a bold move to lessening their ecological footprint.

Keywords : Bamboo, *Bambusia vulgaris, Bambusia bambos,* biomass, renewable energy, gross calorific value, community acceptance.

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LIST OF ABBREVIATIONS

TPER	Total Primary Energy Requirement
TEC	Total Energy Consumption
LPG	Liquefied Petroleum Gas
GCV	Gross Calorific Value
RES	Renewable Energy Sources
GHG	Greenhouse Gases

LIST OF UNITS

ktoe	Kilotonne of oil equivalent
GWh	Gigawatt hours
MJ/kg	Megajoule per kilogram
T/ha/yr	Tonne per hectare per year
GJ/ha/yr	Gigajoule per hectare per year

INTRODUCTION

Background

The Island of Mauritius is situated about 800 km off the east coast of Madagascar at a latitude 20^0 south and longitude 58^0 east. As a result of the general improvement in the standard of living and a sustained economic growth, the overall energy consumption of Mauritius has risen sharply during the recent years. In 2017, the Total Primary Energy Requirement (TPER) and the Total Energy Consumption (TEC) added up to 1,603 ktoe and 982 ktoe respectively. The TPER for the year 2017 was mainly comprised of 57 % petroleum products, 29.4% coal and 13.6% renewables (Statistics Mauritius, 2018). The Republic of Mauritius has no known oil, coal or natural gas reserves, and therefore depends heavily on imported fossil fuels to meet most of its energy requirement.

On an annual basis, the island imports some 900,000 tonnes of petroleum products and 225,000 tonnes of coal which together accounts for 75.4% of the primary energy demand. In 2017, 2,531 ktoe of fossil fuels comprising of 35% coal, 24.6% fuel oil, 13.8% diesel oil 12.8% dual purpose kerosene, 7.3% gasoline and 6.4% Liquefied Petroleum Gas (LPG) were imported. Compared to data from 2016, imports in petroleum products have seen an increase of 11.6% (from 1,474 ktoe to 1,645 ktoe). This conclusively had an impact on the import bills of both petroleum products and coal, where from 2016 to 2017, an increase of 36% (from Rs 21,610 million to Rs 29,406 million) was noted (Statistics Mauritius, 2017; 2018).

Electricity Generation

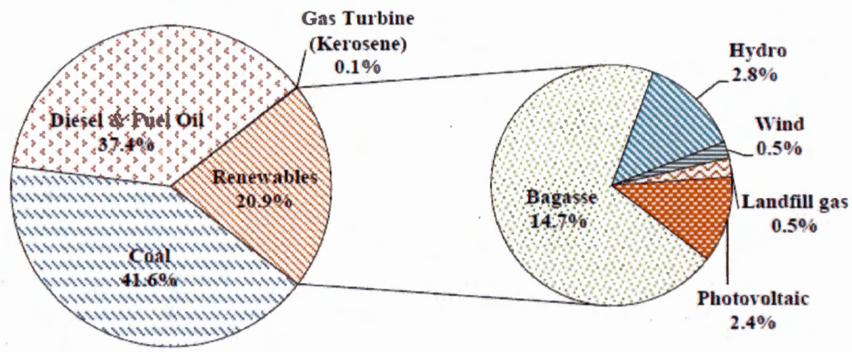

Figure 1 : Percentage share of energy sources in electricity generation, 2017

(Source: Statistics Mauritius, 2018)

In 2017, some 3,157 GWh of electricity was generated. Around 79% (2,496 GWh) of electricity was generated from non-renewable sources, mainly from coal and fuel oil. The remaining 21% (661 GWh) was generated from renewable sources, mostly sugarcane bagasse (Figure 1). Compared to data from 2016, the total electricity generated in 2017 increased by 3.8% (from 3,042 GWh to 3,157 GWh). Electricity generated from coal increased by 3.6% (from 1,267 GWh to 1,312 GWh) and fuel oil and diesel by 6.4% (from 1,110 GWh to 1,181 GWh). On the other hand, however, electricity generated from renewable sources stagnated between the period 2016 and 2017 with 664 GWh and 661 GWh respectively. The latter was mainly due to a decrease of 6.8% (from 497 GWh to 463 GWh) in electricity generated from sugarcane bagasse (Statistics Mauritius, 2017; 2018).

This decrease in sugarcane bagasse can be explained by virtue of the substantial land abandonment by sugar cane cultivators. The nature of these abandonments is mainly due to the fact that the price of sugar on the world market has had a negative impact on the local sugar industry since 2005, forcing farmers to discontinue the traditional crop cultivation. In addition, the last decade has been marked by a shift in traditional sugar cane growing activity to other agricultural and non-agricultural activities by farmers following the new economic conditions prevailing over the island. Land abandonment island-wide by farmers has occurred at an average rate of 500 ha per year (SIFB, 2011).

This change in land use provides, however, with the availability of thousands of hectares of land that could possibly be used for other biofuel crop productions in order to ensure and safeguard the economic return of these abandoned plots of land (To *et al.,* 2018). Here, bamboo could be an interesting fuel crop to be considered for reducing the dependency on imported fossil fuels for energy production. The potential of bamboo as a suitable biomass feedstock has never been explored before in Mauritius, but has proven to be successful in many other countries worldwide.

Bamboo

Bamboo is a term used to describe a large group of woody grasses belonging to the family *Poaceae* and subfamily *Bambusoideae.* They consist of about 1250 species which grow in warm and humid conditions. Bamboos are mostly distributed in the tropic and subtropical regions (including Mauritius Island) and are known for being distinct plants with a wide range of uses. They play a major role in biodiversity conservation and contribute to soil and water management. They require little to no chemical fertilisers and pesticides to thrive and grow, they can tolerate poor soil conditions, grow in degraded plots of land, and self-regenerate themselves at a fast rate, which makes them an important source of biomass (Scurlock *et al.,* 2000).

During the past decades, several studies have investigated the energetic properties of the various species of bamboo worldwide in India, Indonesia, Thailand, China, Chile, Brazil and Africa (Sharma *et al.,* 2018; Sadiku *et al.,* 2016; Darabant *et al.,* 2014; Le, 2014; Kumar & Chandrashekar, 2014; Sritong *et al.,* 2012; Engler *et al.,* 2012 & Das *et al.,* 2008). These sources report that the various species of bamboo have a good potential to be used as biomass feedstock in combustion power plants as they possess desirable fuel characteristics such as low moisture content, low ash content, low chloride content and a higher gross calorific value (GCV) compared to other wood species (eucalyptus, spruce and beech) and most agricultural residues such as straw and grass.

In Mauritius, since the 19th century, many efforts and research work have been invested in finding effective and sustainable supplies of renewable energy. Energetic properties of fuel crops like sugarcane and "Arundo Donax" have been investigated (To *et al.,* 2018). But it is very surprising that bamboo, which is locally available and renowned for their fast-growth rate and high-production yield, has never been considered as a viable source of biomass for bio-energy production.

Aims and objectives

In this context, the main aim of this study is to determine the suitability of two species of bamboo; *Bambusia vulgaris* and *Bambusia bambos* for bio-energy production based on their fuel characteristics. Their relative moisture content, GCV, chloride and ash content are compared to sugarcane bagasse (a by-product from the sugar industry which is currently being used for bio-energy production on the Island) and other agricultural and non agricultural residues mentioned in literature.

In addition, based on literature data, studies have shown that in some cases even where appropriate technology and raw biomass resource were available, some biomass projects still face with resistance due to community opposition (Eswarlal *et al.,* 2014 & Mavrovouniotou, 2015). However, up to date, there is a substantial lack in literature on community acceptance of biomass projects and to our knowledge; no study has been conducted on local community perceptions of bamboo biomass projects. In this retrospect, this study will also shed light on the general Mauritian community acceptance and perception of bamboo biomass as a potential source of renewable energy. Local perceptions of the Mauritian citizens were gathered throughout the study using semi-structured questionnaires.

MATERIALS AND METHODS

Bamboo sampling

Two bamboo plantations located in Mauritius were investigated during this study. The climate prevailing over the island during the study period was mild tropical maritime winter with mean precipitation of 364.4 mm and mean temperature of 20.4^{0}C (MMS, 2018).

Bambusia vulgaris culms of 2.5 years of age were obtained from Mare-La-Chaux located in the eastern region of the island at a latitude of 20.198^0 S and a longitude of 57.749^0 E; and *Bambusia bambos* culms of 5-6.5 years of age were obtained from the experimental site of Omnicane Milling Operations Limited located in the southern region at Savannah at a latitude of 20.485^0 S and a longitude of 57.609^0 E.

Both plantations were grown in furrowed pits of around 30 cm x 30 cm x 30 cm with a spacing of 5-6 m inter-row and 2.5-3 m intra-row with total plant density of around 560 plants per hectare. 10 plots, each 1 m x 1 m at a spacing of 25 m inter-row and 25 m intra-row were established in both fields. The number of shoots per plot varied from 16 – 28. Three (3) shoots were randomly selected per plot and culm ranging from 500 – 2500 g were randomly cut per shoot irrespective of the height (bottom – middle – top), amounting to a total of 60 culms for the two plantation fields (n = 60) (n = 30 per field).

Sugarcane bagasse sampling

Fresh sugarcane bagasse was obtained from Alteo Milling Limited located in the eastern region of the island in Union Flacq. Ten samples weighing 350 – 500g were collected at five collection points (n = 50).

Fuel and residue characterisation

The bamboo and sugarcane bagasse samples were transported to the laboratory in sealed polythene bags where they were oven dried at a temperature of 100 ± 5^0C for 24 hours for moisture content determination. The dried samples were then pulverised and sieved to particle size of about 5 mm. The raw samples were homogenized through thorough mixing and 10 sub-samples weighing 175 – 350 g were taken randomly for each species: *Bambusia vulgaris* (n = 10); *Bambusia bambos* (n = 10); Sugarcane bagasse (n = 10).

Fuel and residual characteristics including GCV, chloride content and ash content of the samples were then determined based on standardised test methods (Table 1).

Table 1: Standard test methods used for fuel and residual characterisation

Parameter	Standard Test Method
Moisture content	ASTM E871-82 (2019)
GCV	ASTM D2015-00 (2000)
Chloride content	Mohr`s Method (2001)
Ash content	ASTM E1755-01 (2015)

Community acceptability and perception

Throughout this study, a research on community acceptance and perception of the Mauritian citizens towards bamboo biomass was conducted using semi-structured questionnaires. Several questions regarding energy generation from fossil fuels and alternative biomass sources of energy, more specifically from bamboo were proposed. A randomly produced sample of 54 respondents (n = 54) with reference to different genders, age groups and area of residence in Mauritius, and who were willing to participate in the study were approached in order to visualize their overall perspectives in regards to green biomass. All of the participants were approached on a fortuitous encounter basis.

The target survey group was selected within the nine districts of the island (Figure 2) and the respondents of the questionnaires were both women and men. On a random encounter basis, three women and three men aged between 18 and 65 years residing in the district of visit and irrespective of their knowledge towards renewable sources of energy and literacy level, were chosen. The languages used during the interviews was Mauritian Creole, English and French. While the chosen sample of 54 respondents did not necessarily represent the Mauritian population as a whole, the survey contributed in furtherance to obtaining a first general impression on acceptance of bamboo biomass for bio-energy production locally. This methodological choice was adopted from a previous study on community acceptance of biomass resources carried out by Mavrovouniotou in 2015.

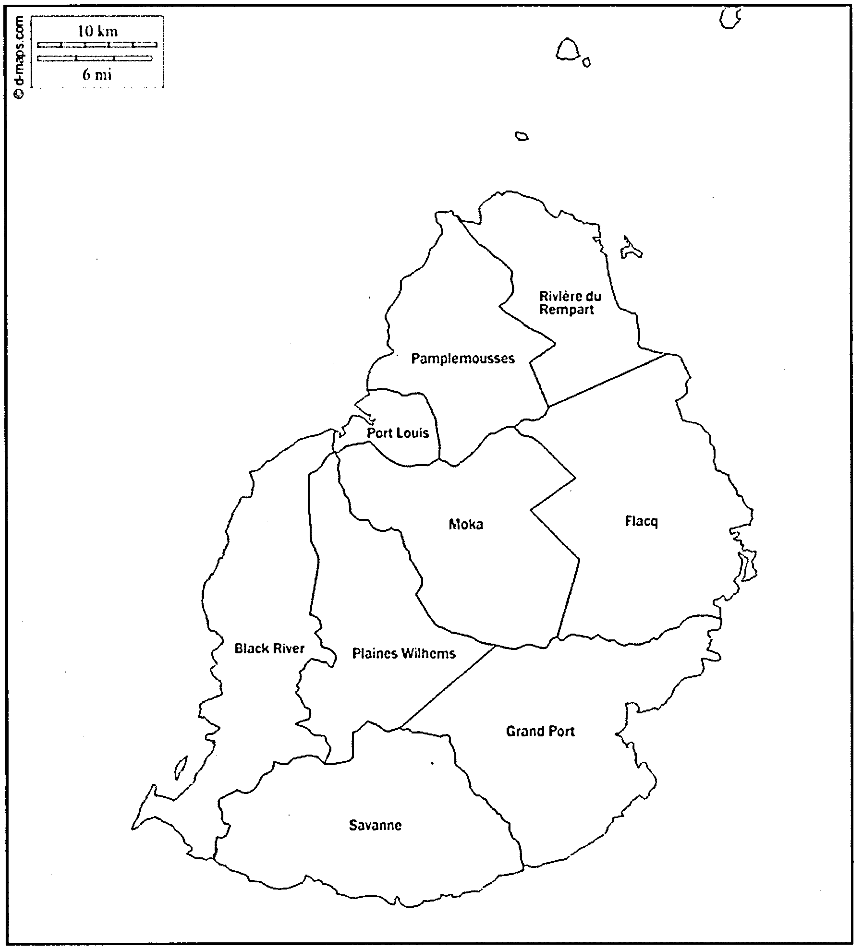

Figure 2: Districts of Mauritius

Source: (D-maps, 2019)

Statistical analysis

The raw data collected was translated to English language and analysed using a thematic analysis. The six-phase framework (1. Data familiarization, 2. Data code identification, 3. Themes identification, 4. Themes reviewal, 5. Defining themes categories; 6. Report production) proposed by Braun & Clarke (2006) was used for themes` coding so as to identify relevant patterns or themes that are important to the research. The empirical data were computed and are presented using matrix display and graphical representations.

RESULTS AND DISCUSSION

In this section, the main findings from the laboratory testing regarding physical and chemical characteristics of the tested samples of *Bambusia vulgaris, Bambusia bambos* and sugarcane bagasse are presented. The respective fuel characteristics of the two species of bamboo will be compared to that of sugarcane bagasse and other agricultural/non agricultural residue from literature to determine their suitability for bioenergy production. Also, the results of the survey carried out on community acceptance and perception of the local citizens regarding the utilization of bamboo biomass is summarised.

Physical and chemical characteristics

Table 2: Sample arithmetic means of physical and chemical analysis of the 10 sub-samples of *Bambusia vulgaris, Bambusia bambos* and sugarcane bagasse.

Species	Age (yrs)	Moisture content (%)	Gross calorific value (MJ / kg)	Chloride content (%)	Ash content (%)
Bambusia vulgaris	2.5	46.3	16.77	0.079	1.34
Bambusia bambos	5-6.5	54.6	17.44	0.062	1.57
Sugarcane bagasse	N/A	46.7	18.33	0.054	3.36

Table 2 above illustrates the sample arithmetic means of analysis including moisture content, GCV, chloride content and ash content for *Bambusia vulgaris* culms of 2.5 years old, *Bambusia bambos* culms of 5–6 years old and sugarcane bagasse.

Gross calorific value

The calorific value of any fuel source is the most eminent parameter to be taken into consideration in the determination of its suitability for energy generation. It provides an indication of the energy chemically bounded in the fuel source, which can be converted into heat energy in combustion systems. Fuel sources with higher calorific values are the most desirable for energy generation (Erol *et al.*, 2010). During this study, the mean GCV of the two tested species of bamboo; *Bambusia vulgaris* and *Bambusia bambos* were found to be 16.77 MJ/kg and 17.44 MJ/kg, respectively. These two values are slightly lower compared to the GCV of locally available sugarcane bagasse (18.33 MJ/kg), but higher than that of other species of bamboo or agricultural/non agricultural sources that are being used worldwide for energetic purposes. For instance, from a study conducted by Sritong *et al.,* in Thailand in 2012, the GCV of the species *Gimsung bamboo* was found to be 15.70 MJ/kg. In another study conducted by Gravalos *et al.,* in 2016, the GCV of Poplar (*Populus euro-america*) and rice straw were measured; and their respective values were 14.43 MJ/kg and 16.48 MJ/kg. In this perspective, the GCV of the two tested species of bamboo seem to be valuable enough and could be considered for energy production

Approximate biomass and energy yield from bamboo and sugarcane bagasse

The results obtained from the GCV testing showed that both tested species of bamboo (*Bambusia vulgaris* and *Bambusia bambos*), when compared to locally available sugarcane bagasse and other biomass feedstock (poplar, rice straw and *Gimsung bamboo*) from relevant literature (Gravalos *et al.,* 2016), have an interesting potential for energy recovery. Based on their relative GCV, the plant density on the collection sites, the average height of each shoot, the average weight and length of each culm, the average number of culms per shoot and the average number of shoots per plot, an estimation of the yield on dry biomass basis (excluding moisture content) and energy yield per hectare per year was calculated. For sugarcane bagasse, based on an estimation that 210 tonnes of sugarcane could be harvested per hectare, and that for each ten tonnes of sugarcane an approximate amount of 3 tonnes of wet bagasse could be yielded (Hofsetz & Silva, 2012 & Soetaert & Vandamme, 2009), its relative GCV and moisture content, an estimate yield of dry biomass and energy per hectare per year was also calculated.

The average biomass yield per hectare per year for *B. vulgaris* and *B. bambos* were found to be 42.8 t/ha/yr and 91.4 t/ha/yr, with respective energy yield of 717.8 GJ/ha/yr and 1587.1 GJ/ha/yr. In the case of sugarcane bagasse, the biomass and energy yield were found to be 45.2 t/ha/yr and 824.9 GJ/ha/yr (Table 3). On comparing these values, it can be deduced that almost the same amount of biomass and energy can be yielded from *B. vulgaris* when compared to sugarcane bagasse, and that twice as much biomass and energy can be harvested from *B. bambos* compared to sugarcane bagasse on a spatio-temporal (hectare/year) basis. This also clearly underlines that both tested species of bamboo have a very good potential to be used as biomass feedstock for bio-energy production.

Table 3: Biomass and energy yield per hectare per year for *Bambusia vulgaris*, *Bambusia bambos* and sugarcane bagasse

Species	Biomass yield (t/ha/yr)	Energy yield (GJ/ha/yr)
B.vulgaris	42,8	717,8
B.bambos	91,4	1587,1
S. bagasse	45,2	824,9

Chloride content

Chloride content present in biomass is another important factor of interest for industrial combustion processes as it may cause adverse effects on the combustion system. Chloride is a naturally occurring element present in biomass and is non-favorable for energy purposes as it enhances the formation and accumulation of deposits, which have corrosive effects on metal surfaces of boilers and furnaces. High chloride concentration is, therefore, not desirable in fuel sources as they may cause slagging of the combustion system (Engler *et al.*,2012; Kumar & Chandrashekar, 2014 & Acharya *et al.,* 2014). From the results obtained from the laboratory testing, on average, the chloride content on absolute dry matter basis for both *Bambusia vulgaris* and *Bambusia bambos* were 0.079% and 0.062% respectively. In comparison, both values are slightly higher than the chloride content of sugarcane bagasse which was found to be 0.054%, but lower than that of other agricultural/non agricultural residues that are currently being used in combustion systems from literature. Both tested species of bamboo showed a chloride content much lower by 32.9 - 69.4% when compared to Miscanthus (0.105%), a perennial grass which is widely sought and used in combustion systems for bio-energy production (Clarke & Preto, 2011).

Ash content

Another important factor, but this time after combustion of fuel sources in combustion systems is the production of solid residue also known as "ashes". The chemical breakdown of biomass fuel source for energy generation, by either thermo-chemical or bio-chemical processes, produces large amount of ashes. As stated by Obernberger & Supancic (2009) and James *et al.,* (2012), the volume of residual matter produced in combustion system is expected to increase over time due to the increasing demand of energy from biomass sources. However, in the long-run, this may result in challenges regarding efficient management of the ashes in terms of storage, disposal and further alternative uses. From the laboratory testing, the respective ash content for *Bambusia vulgaris*, *Bambusia bambos* and sugarcane bagasse were found to be 1.34 %, 1.57% and 3.36%. Thus, the two tested species of bamboo produce 2-2.5 times less residual ashes than sugarcane bagasse. They also have a much lower ash content than other perennial grasses used in combustion systems. Following the study carried out by McKendry in 2002, the relative ash content of Miscanthus and switch-grass were found to be 2.8% and 4.5%. This clearly underlines that harnessing bio-energy from bamboo biomass will result in much lower amounts of residual ashes being produced in combustion systems.

Community acceptance and perception

The first general intention of the survey questionnaires was to assess the initial assumption that the Mauritian citizens are aware of the various issues related to the exploitation of fossil fuels, and the little dissent in their belief towards finding alternative sources of energy that are more environmental-friendly for energy generation.

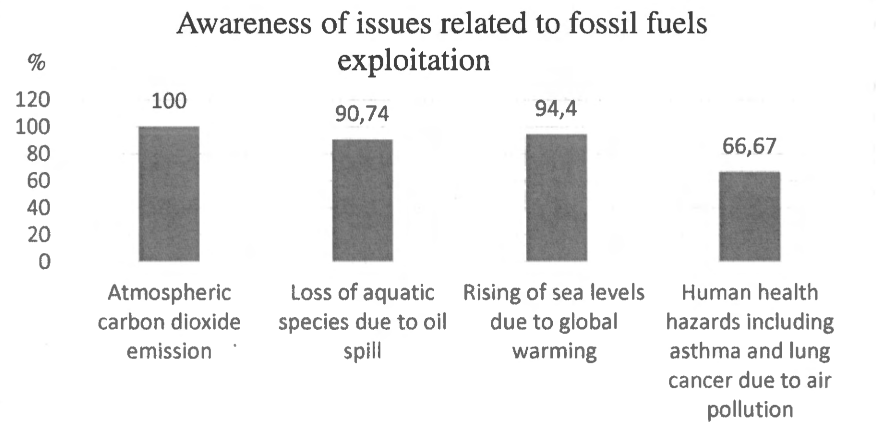

Figure 3: Awareness of the issues related to fossil fuels' exploitation of the 54 respondents

The great majority of the 54 respondents were very much aware of the significant adverse impacts that mining, transportation and burning of fossil fuels have on the environment, the various well-established ecosystems and human health (Figure 3). The main points of concern that emerged during the analysis of the questionnaires were; atmospheric carbon dioxide emission, loss of aquatic species due to oil spill, rising of sea levels due to global warming, and health related issues like asthma and lung cancer due to air pollution.

Furthermore, to draw out the general support towards the usage of renewable energy sources (RES), the participants were asked how willing they were to accept RES in the overall energy generation mix at national level. Results show that there is a high level of acceptance towards the usage of RES. In fact, 91% of the respondents, from which 26 out of females and 23 out of 27 males, were for the usage of RES (Table 4). One possible reason behind this acceptance could be that the participants are very much concerned about the various adverse impacts attached to the utilisation of fossil fuels, and are willing to make a shift to RES in a view to lessening their ecological footprint.

Table 4: Need of finding renewable energy sources (RES) as alternatives to fossil fuels

Need of finding alternatives to fossil fuels that are environmental-friendly for bio-energy production (n=54)				
	In favour: 49 (90.74%)		Against: 5 (9.26%)	
Sex / Age(yrs)	Female	Male	Female	Male
18-40	21	17	0	0
41-65	5	6	1	4

In addition to estimating the respondents` acceptance towards RES for energy generation, we wanted to draw their attention on bamboo biomass as a potential RES. The respondents were asked questions about their awareness of the potential of bamboo as a biomass feedstock and how willing they were to accept bamboo biomass for bio-energy generation locally.

Results show that 81 % of the respondents (21 out of 27 females and 23 out of 27 males) were aware of the suitability of bamboo as a potential biomass feedstock (Table 5). The vast majority of them, especially the 59 % aged between 18-40 years were apprised of, in one way or another of the suitability of bamboo as a potential biomass feedstock for bio-energy production and the various advantages attached to it. This is very interesting as they are aware that they have an abundantly untapped raw renewable resource which is naturally available, cheap, environmentally friendly and which can lead to inclusive societies on their doorsteps.

Table 5: Awareness of the potential of bamboo as a biomass feedstock by the 54 respondents

Awareness of the potential of bamboo as a biomass feedstock (n=54)				
	Aware: 44 (81.48%)		Not aware: 10 (18.52%)	
Sex / Age(yrs)	Female	Male	Female	Male
18-40	17	15	2	3
41-65	4	8	4	1

From the above answers, we have seen that the respondents are very much conscious about the various adverse effects that the exploitation of fossil fuels have on the environment and human health, they support RES and are aware of the capabilities of bamboo as a potential biomass resource. This could probably mean that there would be a positive response in terms of community acceptance towards the implementation of bamboo biomass for bio-energy production locally. As illustrated in table 6, we can see that 80 % of the respondents (20 out of 27 females and 22 out of 27 males) were in favour of implementing bamboo biomass for bio-energy production locally. They even provided us with some interesting testimonies in support of their decisions and two of them which sum up their general opinion are presented below;

1. "Bamboo is a naturally occurring species and it can be found everywhere on the island. Many African countries like Ethiopia or even Ghana have already started implementing interesting projects where bio-energy is being produced from bamboo so as to support underprivileged areas in terms of electricity. This is also helping the local communities to increase their house-hold revenues as numerous jobs are being created. People can live a decent life and children can

to go to school. Here in Mauritius we have the appropriate technologies and we have the raw resource, why don`t we capitalise on it?"

2. "It is sad to say but I think that bamboo is a completely under-looked raw resource in Mauritius. In the quest of finding cleaner sources of energy, empowering local societies, providing the poor with electricity, restoring degraded and marginal plots of lands, restoring areas affected by soil erosion, restoring biodiversity or even just countering effects of deforestation, bamboo has proven to be very effective worldwide. Here, we are a tropical Island and all the conditions are ideal for them to grow. As a matter of fact, they can be found almost everywhere around the Island, be it in the Eastern, Western, Northern and Southern regions. Still, we don`t exploit them."

On the other hand, the 20 % of respondents who were not in favor of the implementation of bamboo biomass for bio-energy production evoked reasons such as;

1. Inefficiency of biomass fuels (in general) compared to fossil fuels
2. Bioenergy competition with food and land security
3. Possible loss of biodiversity due to monoculture, and;
4. Insufficient land availability for mass culture

Table 6: Appreciation of bamboo biomass for bio-energy production by the 54 respondents

Appreciation of bamboo biomass for bio-energy production by the 54 respondents				
	In favour: 43 (79.63%)		Against: 11 (20.37%)	
Sex / Age(yrs)	Female	Male	Female	Male
18-40	17	15	2	4
41-65	3	7	5	1

Finally, the respondents were asked, irrespective of their appreciation for bamboo biomass to be used for bio-energy production locally, their general expectations if any in case of a possible implementation of such projects. 67 % of the participants were for a much lower cost of electricity, 63 %, for providing youngsters with job opportunities, 66 %, for respecting and ensuring environmental protection, and 40 %, for the preservation of the heritage landscape (also in figure 4).

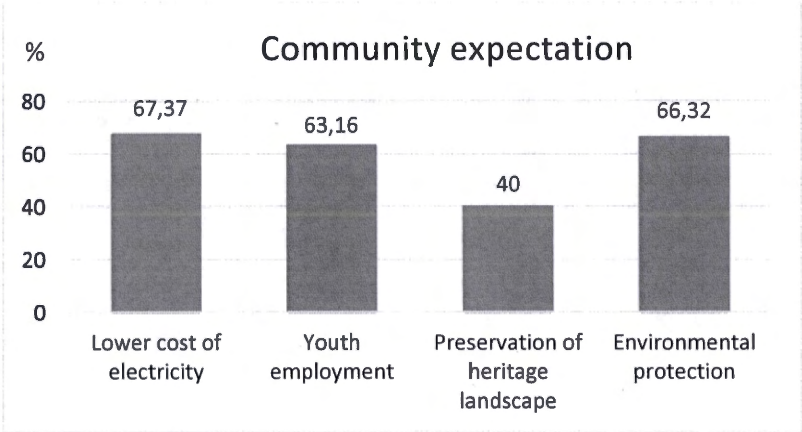

Figure 4: General expectations of the 54 respondents in case of a possible implementation of bamboo biomass for bio-energy production.

CONCLUSION

The study shows that both tested species of bamboo; *Bambusia vulgaris* and *Bambusia bambos,* are potentially suitable for bio-energy production. They share desirable fuel characteristics when compared to locally available sugarcane bagasse and other agricultural/non agricultural species which are currently being used for energy production worldwide. They possess interesting gross calorific values (16.77 MJ/kg for *Bambusia vulgaris* and 17.44 MJ/kg for *Bambusia* bambos) which make them valuable fuel sources to be considered for bio-energy production. Their relatively low chloride content (0.079 % for *Bambusia vulgaris* and 0.062 % for *Bambusia bambos*) make them appropriate for combustion systems as this can reduce the formation and accumulation of deposits on metal surfaces of boiler and furnaces, hence reducing the risk of slagging of the combustion systems. They also possess a relatively low ash content (1.34 % for *Bambusia vulgaris* and 1.57 % for *Bambusia bambos*) which means that harnessing bioenergy from these two species may result in much lesser amount of residual ashes being produced, stored and disposed of. In addition, their average biomass and energy yield per hectare per year (42.8 t/ha/yr and 717.8 GJ/ha/yr for *B. vulgaris,* 91.4 t/ha/yr and 1587.1 GJ/ha/yr for *B. bambos*) when compared to sugarcane bagasse (45.2 t/ha/yr and 824.9 GJ/ha/yr) is very interesting as approximately the same amount of biomass and energy can be yielded from *Bambusia vulgaris* and sugarcane bagasse, and twice from *Bambusia bambos* on a spatio-temporal basis. In terms of community acceptance, when it comes to making a shift towards renewable sources of energy that are more environmentally friendly compared to fossil fuels, and in a view of lessening their ecological footprint, we have seen that acceptance is relatively high. 91 % of the respondents supported the implementation of more RES in the energy generation mix at national level. Regarding the utilisation of bamboo biomass, we can ratiocinate in general from the survey that the awareness of its suitability and the willingness to accept it as a potential bio-fuel source is present. Here, we have seen that 80% of the respondents were in favour of its utilization for bio-energy production locally.

Personal perspective

Bamboo is globally renowned as being one of the fastest-growing plant in the world and is capable of achieving full maturity in only few years when compared to trees which need decades to grow. They can tolerate poor soil conditions, grow in wide range of environment, they need little to no chemical pesticides and fertilisers to grow, they require little to no irrigation to thrive, and they can self-regenerate themselves at a very fast rate after being harvested. This fascinating plant has a myriad of applications ranging from producing biomass for energy generation, charcoal, timber, high quality textile fabrics, furniture, flooring, musical instruments, kitchen utensils, scaffolders, food and many more. They are also used to counter soil erosion, afforest areas severely affected by deforestation, and due to their fast-growth rate, they produce to about 35% more oxygen than other trees and sequester carbon dioxide at a very high rate. These multiple uses have helped in providing people with many job opportunities and has led to social, economic and environmental stability.

In the context of Mauritius, we have seen a sustained economic growth over the past decades which has led to an increase in the overall energy consumption. It might be very interesting to consider bamboo plantations on the abandoned plots of land by sugarcane planters for energy production so as to meet the overall energetic demand. Also, the plantations could be used in many other ways. Since the island has been severely affected by deforestation ever since the visit of the Dutch in the year 1598, they might play a vital role in afforesting many areas over the island. They could also help in sequestering carbon dioxide and prevent soil and wind erosion due to their dense root system. Part of the plantations could even be used to produce timber, plywood, furniture, textile fabrics thus opening doors to many job opportunities. Considering the manifold advantages that bamboo offers, its use as a source of renewable energy would definitely be beneficial to Mauritius in terms of framing inclusive societies and building economic as well as environmental growth.

Recommendations

Since bamboo has never been exploited before with a bio-energy prospect in Mauritius, no studies have been conducted on its social, economic and ecological feasibility. Recommendations would thus be to pursue further investigations on the production and management of bamboo plantations in terms of what species would be best suited for bio-energy production. The identification of potential areas where bamboo could be planted and harvested are also recommended. An in-depth life cycle analysis including the cost of production, maintenance of the bamboo plantations, harvest, storage, transportation, processing of the bamboo biomass and disposal of ashes would also be needed. Finally, studies on profit margins and return of investment especially for farmers who would like to embark in bamboo cultivation could also be very interesting and useful.

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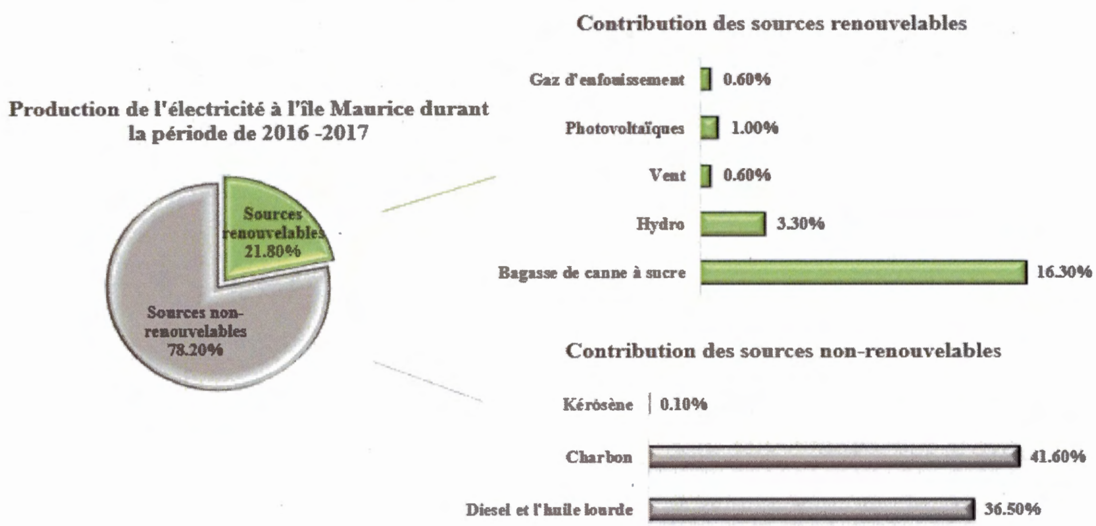
ANNEX

Annex 1 : Questionnaire

Questionnaire sur les perceptions des citoyennes / citoyens de l'île Maurice quant aux impacts associés à l'utilisation de combustibles fossiles et à l'éventuelle possibilité d'utiliser le bambou comme biocombustible alternatif pour la production d'énergie.

Partie 1 : Impacts des combustibles fossiles sur les systèmes biophysiques et humains

Voici une mise en contexte avec quelques brèves informations sur la production d'électricité à l'île Maurice durant la période de 2016-2017.



Source : (Statistiques Maurice, 2017)

Questions

1. Pensez-vous que l'utilisation de combustibles fossiles (de sources non renouvelables) puisse engendrer des impacts négatifs significatifs sur l'environnement et les humains tels que :

- L'émission de CO_2 dans l'atmosphère.

  Oui ☐ Non ☐
- Le réchauffement planétaire.

  Oui ☐ Non ☐
- La fonte des calottes polaires.

  Oui ☐ Non ☐
- La hausse du niveau des mers.

  Oui ☐ Non ☐
- La mort d'espèces aquatiques causée par le déversement de pétrole durant le transport maritime et l'utilisation d'explosifs pour accéder aux puits de pétrole.

  Oui ☐ Non ☐
- Des complications de santé chez l'être humain incluant l'asthme, le cancer pulmonaire, des maladies cardiovasculaires, etc.

  Oui ☐ Non ☐

2. Pensez – vous qu'il est important de trouver des alternatives aux combustibles fossiles pour produire de l'énergie ?

Oui ☐ Non ☐

Partie 2 : Le bambou – une plante utile ?

Questions

1. Pensez-vous que la condition générale des sols à l'île Maurice pourrait être favorable à la bonne croissance du bambou ? Pourquoi ?

   Oui, ☐

   ....

   ....

   ....

   Non, ☐

   ....

   ....

   ....

2. Pensez-vous que le bambou pourrait fixer plus de carbone et générer plus d'oxygène que n'importe quelle autre plante par unité de temps et d'espace ? Pourquoi ?

   Oui, ☐

   ....

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   ....

   Non, ☐

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3. Pensez-vous que le bambou pourrait être une source significative de biomasse combustible pour la production d'énergie ? Pourquoi ?

   Oui, ☐

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   ....

   Non, ☐

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4. Selon-vous, quels seraient les avantages associés au bambou à l'Île Maurice ?

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5. Selon-vous, quels seraient les désavantages associés au bambou à l'Île Maurice ?

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6. Dans l'éventualité où le bambou serait utilisé pour la production d'énergie à l'île Maurice, indiquez en ordre de priorité (1 étant le plus important et 5 le moins important) vos attentes d'un tel projet.

   - Le respect du paysage patrimonial ☐
   - Protection de l'intégrité de l'environnement ☐
   - Coût moindre de l'électricité ☐
   - Protection de la santé humaine ☐
   - Génération d'emplois pour les jeunes ☐

7. Avez-vous d'autres attentes reliées au bambou à l'Île Maurice. Si oui, lesquelles ?

   Oui, ☐

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   ……………………………………………………………………………………………

   Non, ☐

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

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8. Sur un plan général, seriez-vous pour ou contre l'utilisation du bambou pour générer de l'énergie et pourquoi ?

   Pour, ☐

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

   Contre, ☐

   ……………………………………………………………………………………………

   ……………………………………………………………………………………………

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Partie 3 : Mieux vous connaître

Questions

1. Âge :18 – 25 ☐ 26 – 40 ☐ 41 – 60 ☐ 61 et plus ☐

2. Sexe : F ☐ M ☐

3. Nationalité : Mauricienne ☐ Autre ☐ ....

Nous vous remercions sincèrement du temps accordé et de votre collaboration à ce questionnaire.