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ABSTRACT

Wild Cane (Arundo donax) is a perennial rhizomatous grass that is native to tropical and sub-tropical zones. This C3 crop is known to have significant potential to produce commercial grade bioenergy. Belize has conducted a preliminary compatibility test at the American Sugar Refineries/ Belize Sugar Industries, Belize Co-generation Energy Ltd. (ASR/BSI BELCOGEN) facility which produced satisfactory but inconclusive results. The potential of this species as an energy crop is enhanced by its versatility, adaptability and its robustness to climate variability. Further, the crop's resistance to environmental stresses and its ability to flourish on marginal spaces means that successful propagation will not lead to competition for productive agricultural lands, and potentially consequential negative effects on Belize's food security.

The goal of this study was to evaluate the feasibility of the commercial cultivation of Arundo donax as an alternate fuel source for cogeneration at BELCOGEN in Belize, focusing particularly on biomass yield and the identification of climate and other environmental factors required for optimum growth. In this regard, the research examined three sites comprising natural stands of Arundo donax - Middlesex, Sittee River and Monkey River. The species demonstrated good productivity potential particularly within the Middlesex and Sittee River areas. Biomass yield was estimated at 15.18 t ac-1, 4.76 t ac-1 and 3.45 t ac-1 for Middlesex, Sittee River and Monkey River, respectively. In this study, the main parameters examined were climatic conditions and soil analysis, specifically moisture content, soil type and pH. Different growth patterns were noted at the three sites with the number of stems and extrapolated yield varying from 9.8 t ac-1, 10.45 t ac-1 and 32.02 t ac-1 for Monkey River, Sittee River and Middlesex, respectively. The adaptability of the species to marginal lands, the limited human input needed for its cultivation, and its high biomass yield are factors which make Arundo donax a potentially viable fuel crop.

Keywords: Arundo donax; Caribbean Community Climate Change Centre; Belize; renewable energy; mitigation

INTRODUCTION 1.0

According to the IPCC's AR5, climate change has the potential to cause substantial impacts on the design and operation of energy sourcing and its delivery facilities [1]. In the Caribbean, the changing climate has presented increasing challenges to the energy sector, especially its production and transmission. In 2008, it was estimated that over US$ 14 billion would have been spent for the importation of fossil fuels, providing over 90% of energy consumed in CARICOM countries [2]. Even though total greenhouse gas emissions from the CARICOM states are extremely small, the region has committed to reducing its carbon footprint significantly, primarily through an ongoing process of transitioning away from fossil fuel use in the electricity sector [3,4,5]. While there is presently more emphasis being placed on the exploitation of solar thermal, solar photovoltaic and wind energy potential, bioenergy production for direct combustion and cogeneration is another potentially viable renewable energy source that has begun to attract the attention of the energy sector.

1.1 CARIBBEAN ENERGY SECTOR

The Caribbean region is heavily dependent on the use of imported fossil fuel, mainly refined petroleum products [6]. Over the last several decades, the region's fossil fuel use has resulted in the markedly increasing cost of energy, in part due to highly unpredictable global market prices for the commodity [7]. Electricity cost in the Caribbean is approximately four times or 80% higher than most developed countries, with the average tariff between 2002 and 2012 surpassing US$0.34 per Kwh [7]. This cost is almost twice the Latin America and Caribbean (LAC) average of approximately US$0.18 per Kwh [7]. According to the World Bank, 2018 [8], 7-20% of national GDP expended by most of the Eastern Caribbean islands is due to the high dependency on petroleum products for energy generation. In some states this accounts for as much as 50% of export revenue and demand is expected to rise further to 3.7% per year, doubling by 2028 [9,10]. With a modest increase in economic growth in the Caribbean, it is projected that by 2030 there will be greater demand for electricity, estimated at approximately 1,500 terawatt-hours (TWh) from a 2008 baseline of approximately 625 TWh [11]. As a result of this dependence on fossil fuels, the Caribbean region faces a critical energy challenge [12]. With the exceptions of Trinidad and Tobago, Guyana, Suriname, Barbados and Belize there are no as yet proven oil and natural gas reserves in other CARICOM states [13,14,15].

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The dependency on imported fossil fuels and associated price volatility therefore have significant implications for regional security. There is an urgent need for energy efficiency programmes in the Caribbean that would incentivise savings, improve the countries' financial situation and attract investments within the sectors that are responsible for most of the CO2 emissions [16]. There are great prospects for efficiency within the energy sector from wind, geothermal, hydro and biomass sources that have the potential to be less costly than power generation based on fossil fuels [9]. For some time now a number of islands within the Caribbean have employed the use of renewable energy technologies with Jamaica, Barbados and Grenada highlighted by Shirley & Kammen, 2013 [3] to be among the pioneering countries in the region. These have successfully implemented initiatives using solar photovoltaics, solar thermal water heating and wind energy (Figure 1). The case studies based on these initiatives and presented by Shirley and Kammen, 2013 [3] corroborate the findings of Nexant, 2010 [9] which demonstrate that all but two of the renewable energy projects to be significantly less costly than if they were based on fossil fuels.

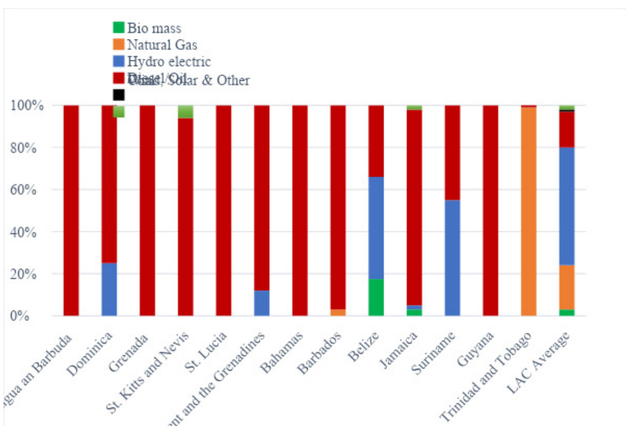

Figure 1: Installed energy generation within the Caribbean. Source: [7]

Clean energy development and innovations are largely understudied within the Caribbean region, which has considerable development potential. For instance, given the region's high average insolation of approximately 15-20MJm-2 day-1there is enough insolation to potentially produce the region's entire energy requirements from solar sources alone [3,17,18]. As part of the region's effort to enhance energy efficiency and reduce energy costs, the Caribbean is already exploring viable renewable energy technologies that include wind, biomass and solar. In the last decade and a half some countries in the Eastern Caribbean have also been exploring the use of geothermal power, while hydropower already makes an important contribution in other states including Dominica, Guyana and Belize [7,19].

1.2 BELIZE ENERGY SECTOR

Belize's energy potential, like the rest of the Caribbean region, is very much underexploited [20]. The country has substantial wind resource potential and an estimated 75-100 MW of hydropower in addition to the existing 54 MW [20,21]. With the growing economic expansion, however, the country faces high energy costs and the high level of population growth suggests that energy demand will rise to approximately 4% per annum in the future years [22,23]. In 2018 the Public Utilities Commission (PUC) granted Belize Electricity Limited (BEL) a 4.4% increase in the electricity tariff and by 2010 the cost of electricity was approximately US$0.44 per kilowatt-hour.

Belize's electricity cost is among the highest within Central America, a challenge that is compounded somewhat by the country's declining petroleum production. However, as a result of its existing renewable energy projects, Belize's electricity rates are on average lower than for most of the rest of the Caribbean region [20,24]. In 2016, approximately 55% of Belize's domestic grid capacity (155MW) was supplied by BEL, the sole transmission and distribution entity, through hydropower and biomass power generation, augmented with imported power from Mexico's Comisión Federal de Electricidad [22]. This renewable energy component accounted for approximately 37% of the total electricity output in 2017 [25]. According to the PUC, in 2015 output based on fossil fuels accounted for 68.5MW of Belize's electricity capacity, followed by small hydro (54.3MW), biomass and waste (31.5MW) and solar (0.5MW) [25].

Just over half the country's electricity needs are generated from renewable energy (hydroelectric and biomass) by Independent Power Producers (IPPs), from which BEL sources 71.5% of its distribution capacity [26]. Table 1 lists these IPPs and their contribution to Belize's electricity grid. It has been pointed out, however, that although hydropower and biomass are excellent energy sources as a result their reduced Greenhouse Gases (GHGs) emissions reduction in a number of air pollutants and the provision of more usable energy; climate change poses substantial risks to future electricity production from these sources, especially given a projected increase in the frequency and duration of droughts [27,28,29].

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Table 1: Renewable energy sources and their production capacity Source: [24,26]

Independent Power Producers (IPP)	Energy Production (MW)
Mollejon Hydro Plant	25.5MW
Chalillo Hydroelectric Dam Plant	14.0 MW
Vaca Hydroelectric Facilities	19.0 MW
Hydro Maya Dam	3.5 MW
BELCOGEN	13.5 MW

1.3 DESCRIPTION OF ARUNDO DONAX

Arundo donax, commonly called 'wild cane' because of its resemblance to Saccharum officinarum (sugar cane), is a perennial and is the largest of the herbaceous grasses [30]. The plant's documented presence in Belize dates back to 1883 and it has remained a part of the ecosystem for over 130 years, covering almost 2% of Belize total land area [29,31]. The plant material is of cultural importance to Belize where it is used for fuel, craft and in construction. This grass grows to an approximate height of 2-10m with a very strong rhizobium root from which fibrous roots extend, penetrating deep into the soil [32]. The stems are partitioned by nodes each being approximately 12-30 cm, as in sugar cane or bamboo with the diameter ranging between 1-4cm. The walls are approximately 2-7mm thick with leaves in a single plane and alternating throughout the culm [30,32]. These leaves are broad-based and taper to a fine point at the end, while the sheaths are tightly wrapped around the stems [33,34]. Its attractiveness for biomass utilisation is as a result of its aggressive growth rate, particularly within riparian areas. Despite being declared invasive species by the World Bank [29], the propagation of Arundo donax can be easily controlled, even though its sterile seeds are dispersed substantial distances by wind [35,36,37].

1.4 ENERGY POTENTIAL OF ARUNDO DONAX

Renewable Energy Technologies (RETs) within the Caribbean have a long history dating back to the 17th Century when sugar cane made its debut, with the utilisation of bagasse and rice husk as biomass energy [38]. According to Lemons e Silva, 2015 [39], Arundo donax has been described as a very promising grassy plant with the ability to be used as a renewable energy source, partly because of its ability to thrive in dissimilar soil types and climatic conditions, as well as its fast growth rate. Evidence from several studies confirms that Arundo donax is among the leading lignocellulosic biomass sources within tropical, subtropical and Mediterranean regions, and thrives well on marginal lands [35,40,41]. The plant exhibits high yield potential per hectare compared to other potential energy crops, extremely low or limited ecological/climatic demands, is extremely tolerant to a wide range of soil types. It is tolerant of saline soils and water-logged conditions and has low nutrient requirements. Given the ability to grow in marginal areas, it does not compete with food crops that require arable land. Arundo donax is pollen-free, which eliminates the risk of cross-fertilization, makes it a stable genotype and reduces invasiveness. The high potential of Arundo donax as a fuel crop was demonstrated from extensive studies done by Lemons e silva et al., 2015 [39], Pilu et al., 2014 [41] and Angelini et al., 2009 [42]. Arundo donax is quite versatile and capable of being utilised in its solid form as biofuel in direct combustion [43], or further processed to produce biogas in anaerobic fermentation and bioethanol when subjected to alcoholic fermentation [44,45].

1.5 CULTIVATION OF ARUNDO DONAX UNDER CONTROLLED AGRONOMIC

Even though Arundo donax has the ability to grow in a wide range of pedoclimatic conditions, adequate field preparation is still required [46]. This has led to further investigations, including on the effect of fertilisation on fuel quality and biomass yield [47,48]. Angelini et al, 2005 [48] further investigated the impacts of management practices on biomass yield and energy balance of Arundo donax, by monitoring variations in crop yield in response to fertilizer, plant density and harvest time. They concluded that fertilization had a positive impact on enhancing dry biomass yield at low planting density, when compared to the non-fertilized crops. Impagliazzo et al., 2017 [49] validated this finding and further found that the presence of Arundo donax tended to improve soil quality and increase carbon storage in the soil, suggesting that it might be beneficial in climate change mitigation. Similarly, the work of Riffaldi et al., 2010 [50] showed that Arundo donax also has the ability to improve organic matter content and microbial biomass.

Burner et al., 2015 [51] compared the biomass yield of Arundo donax, Miscanthus giganteus and Miscanthus spp., with and without irrigation and seasonal harvesting, in order to assess its potential to be utilised as a bio-energy feedstock. It was found that when irrigation was applied, Arundo donax was the most productive crop, yielding the greatest increase in total dry biomass, the largest stalk diameters and tallest stalks. DiMola et al., 2018 [52] tested the crop's salinity tolerance, a critical measure of the crop's adaptability. It was determined that the level of saline stress did not cause any difference in biomass yield compared to the control. In fact, yield loss of approximately 50% only occurred at very high salinity levels, suggesting that the plant would be tolerant of increasing salinity under a changing climate.

In 2018, the Caribbean Community Climate Change Centre (CCCCC) was awarded a grant under the Project Preparation Facility (PPF) of the Green Climate Fund (GCF) to enable Belize

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to develop and implement the "Arundo donax Renewable Bio-mass Fuel for Belize Project, aimed at investigating and demonstrating the efficacy of Arundo donax as a renewable energy source [53]. A study conducted by Daniels, 2016 [54], in collaboration with the CCCCC and Belize Cogeneration Limited (BELCOGEN), revealed that the combustion of Arundo donax for electricity generation was a viable proposition for increasing Belize's renewable energy contribution to the energy sector. Incorporating the results of Daniels, 2016 [54] and other relevant findings reported in the literature, this paper focuses on some of the critical areas recommended for further investigation. Among the gaps identified was the need for additional work to determine growth rates and potential biomass yields of the 'wild cane', when cultivated under controlled agronomic and different field management strategies.

METHODOLOGY 2.0

2.1 STUDY AREA

Belize is the only CARICOM state that is located within the Central American region. It is bounded by the Caribbean Sea, Mexico and Guatemala. It covers an area of approximately 22,965 km2 (8,867 mi2) and has a population of approximately 398,050 as of mid-year 2018 [55]. The study was conducted in the Sittee River and Middlesex areas within the Stann Creek District and Monkey River in the Toledo District (Figure 2) where, excluding the stipulated 66ft buffer zone, natural stands of Arundo donax were identified in sufficient quantities for both the study and the compatibility testing at BELCOGEN. These were chosen primarily for the ease of access (road network), and the proliferation of mature stands of Arundo donax that could be harvested. Spectral analysis showed that Arundo donax accounted for approximately 354 km2 or 1.54% of Belize's total land area [56].

According to King et al.,1989 [57], the study areas within the Stann Creek District receives a mean annual rainfall of 2000 mm in coastal areas. The total increases to 3000 mm going westward into the mountains, which is higher than for most of Belize, but not as high as the average annual rainfall received in the Toledo District.

2.2 SITE SELECTION AND PREPARATION

Sampling plots were established within the Middlesex (N17.01694 N88.48428, N17.01702 W88.48441) and Sittee River (N16.83223 W88.28837, N16.831, N16.83095 W88.28776) areas, both located within the Stann Creek District, and Monkey River (N16.37911 W88.50781) situated within the Toledo District. Spectrum imagery evidence confirmed the widespread existence of Arundo donax at the three previously identified sites, within the flood plains of the Toledo and Stann Creek Districts [58]. Reconnaissance was conducted to ascertain accessibility to areas with mature stands of Arundo donax that would be harvested while conforming to a 66ft buffer zone along the waterways. Duplicate experimental plots were temporarily set out within the Middlesex and Sittee River areas with natural stands of Arundo donax and one within the Monkey River area. Sample plots of approximately 9.29m2 (100ft2) were established at each site. All samples of Arundo donax within these plots were harvested by cutting stalks at approximately 0.15m (0.5ft) above the soil surface, based on the method used by Burner et al., 2015 [51]. The apical shoots were all severed at the last green leaf sheath attachment from the stem samples. Subsequent to removing the apical shoots, they were evaluated for length, weight and stem counts, all taken to establish averages. For each site, the following averages were recorded: number, weight, length and diameter of stems.

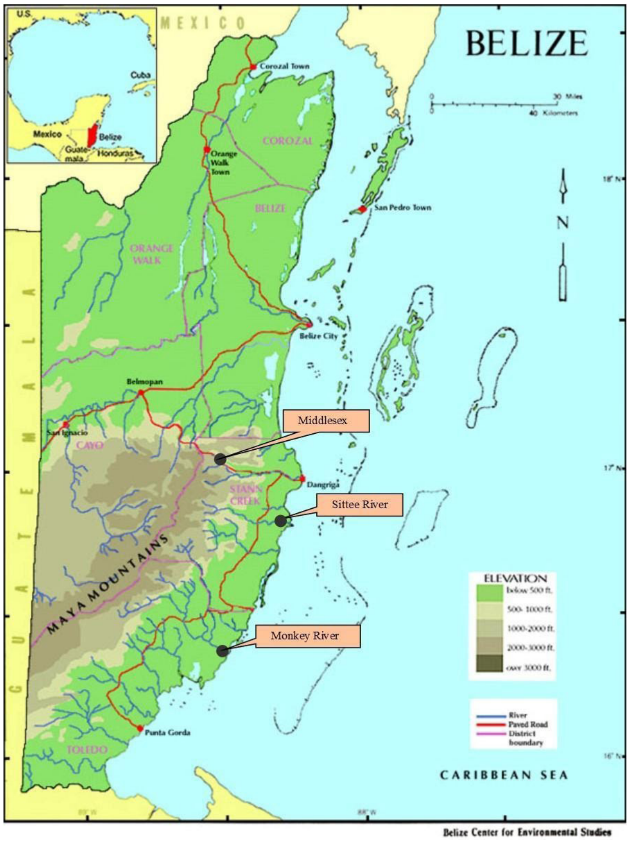

Figure 2: Location of study sites with mature natural stands of Arundo donax. Source: [53]

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2.3 SOIL SAMPLES AND MOISTURE CONTENT

Soil samples at each of the three sites were taken at a depth range from surface to-152.4mm and analysed for Nitrogen (N), Phosphorous (P), Potassium (K), Potential hydrogen (pH) and moisture content. From each sample plot, two stems were selected, and the biomass milled (shredded). The bio-matter was weighed before being placed in Pyrex beakers and dried in an oven at a constant temperature of 103oC. From each stem, one hundred grams (100g) of shredded biomass was utilized, if available or practical. If the 100g requirement could not be met, the entire sample was used and dried to a consistent weight. The mass was weighed to the nearest 1g or 0.001kg and the moisture content calculated (Box 1). The moisture content analysis was conducted by the Science Department Laboratory at the University of Belize (UB), Belmopan.

BOX 1: UB's procedure for moisture content determination of *Arundo donax* by oven dry method.

- Wet weight of biomass sample
- Oven-dry biomass sample for 12 hours at 103°C
- Dry weight of biomass sample
- Weight of water (Wet weight – Dry weight)
- Moisture Content (%) = $\frac{\text{Weight of water}}{\text{Wet weight}}$ x 100

2.4 METEOROLOGICAL CONDITIONS

To evaluate the climate associated with Arundo donax growth and development, the spatial variation in rainfall and temperature, including means and extremes, as well as the associated long- and short-term fluctuations were assessed.

2.5 STATISTICAL ANALYSIS

For the Monkey River and Sittee River sites, soil samples were taken and the soil moisture content compared with that for similar soil types at the closest agro-meteorological stations. In this case, soil moisture content for the Sittee River and Monkey River samples were compared with soil moisture data from the Melinda Forest and Savannah Forest stations, respectively. Significance testing was performed to evaluate the extent to which the data could be considered representative of the sites.

RESULTS AND DISCUSSION 3.0

3.1 BIOMASS YIELD AND SOIL PARAMETERS

Results from the three sites (Monkey River, Sittee River and Middlesex) indicated that biomass yield was significantly higher for the Middlesex samples when compared to those obtained from the Sittee River and Monkey River sites (Figure 3). Collectively, the number of stems, diameter and length of samples from the Middlesex were larger and significantly more mature than for the other sites (Figure 4). The samples from Monkey River had the highest number of stems (65) but recorded the smallest diameters and average length. Considering that all sites have similar environmental exposure (i.e. sunshine duration and water availability), it is likely that the relatively greater competition for resources at the former locations may partly explain the lower stem numbers at Sittee and Middlesex, when compared with Monkey River. Stem numbers for Middlesex averaged 7.5 stems per m2, which contrasts significantly with the findings of Dalianis, 1996 [59], whose research suggested that approximately 50 stems per m2 could be extracted at native sites. The Monkey River site is noted for its high level of vegetative growth (other species of grasses and broadleaf plants) and large culms of Arundo donax, indicating a high level of competition for resources among species. The low stem numbers for Middlesex would also be expected to be associated with a reduction in diameter and lower biomass yield, compared to the other two sites.

In contrast, Sittee River sample plots were located approximately 100 feet from the Riverbank, and it was evident from field observations that burning occurred frequently. The samples were a mixture of mature and younger stock with the majority from the latter group. The fire-resistant nature of the plant allows only the removal the top growth by fire which hardly affects the extensive rhizomes that sprout quickly thereafter [30,60]. It is speculated that this is more favourable for the regeneration of Arundo donax than for native riparian species [60]. As such, this may have accounted for the high number of younger shoots emerging from the burnt area, given the reduced competition for resources after fires which would have eradicated competing non fire-resistant vegetation. As for the Middlesex plots, they were in a region where cattle grazing occurs. Consequently, the nutrients from the animal manure would have contributed to the growth and development of Arundo donax, reflected by enhanced lengths and diameters, averaging 4.01m and 3.04cm respectively, the highest for the three locations.

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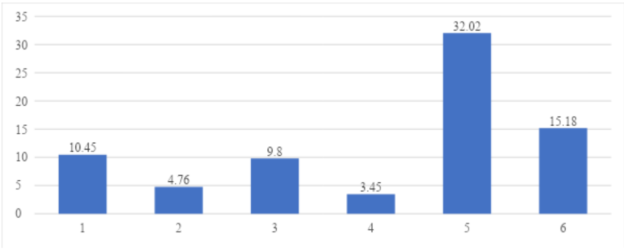

Figure 3: Dry and Fresh biomass yields (ton ac-1) of Arundo donax samples from Middlesex, Sittee and Monkey Rivers

Growth was noticeably more robust at Middlesex, where individual plant heights averaged 4m, in line with the findings of Christou et al., 2001[61] who reported heights of approximating 5m under native site conditions. In contrast, the average plant height for both Sittee and Monkey Rivers was approximately 2.8m (Figure 4).

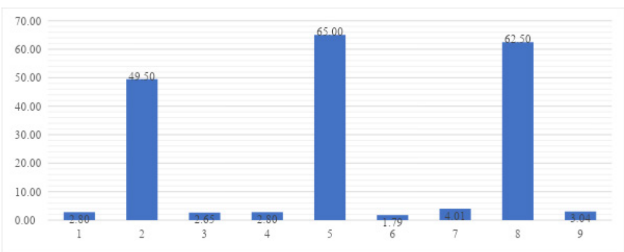

Figure 4: Number of stems, length (m) and diameter (cm) averages from the three research sites

The results of soil acidity analysis for Middlesex and Monkey Rivers showed pH of 6.025 and 7.34, respectively (Table 2). These values were consistent with those recorded by DiTomaso, 1998 [62], in which it was found that Arundo donax thrived well on soils with pH ranging from 5 to 8.7. Perdue, 1958 [33] highlighted that the crop thrives well where water is located or even near the surface. In all areas where Arundo donax was observed to be growing, there were water bodies in close proximity. In particular, the Middlesex field plots were located within a flood plain, and it is presumed that flood waters are the primary transport by which the rhizomes are dispersed for propagation along the banks of the North Stann Creek River.

Sittee River soil samples had a relatively high nitrogen content, and the high moisture content suggests that inorganic nitrogen may be added to the soil through atmospheric deposition by rainfall, especially during the rainy season. Such depositions can be substantial [63]. In addition, both Sittee River and Middlesex are prone to flooding [58], and during the rainy season, it would be expected that the flow rate of the North Stann Creek River would increase due to augmented runoff from land. In this regard, it is likely that upstream farmland activities could also be the source of nitrogen, from the periodic application of fertilizers to the soils. This additional nitrogen would likely enhance plant growth downstream, especially during the rainy season when the surrounding areas are flooded. The higher phosphorus content at Sittee River may partly be attributed to the high incidence of burning known to occur in the area but much less so at the other two locations. Climatic and site conditions including rainfall, temperature, soil moisture, soil aeration and salinity affect the availability of phosphorus. Generally, soils with pH values ranging between 6 and 7.5 are regarded as ideal for phosphorus availability [64], while pH below 5.5 as in the case of Sittee River (pH 4.4) is a limiting factor, as it hinders P mineralisation from organic matter decomposition.
Soils from the Middlesex and Monkey River plots were determined to be a mixture of sand and clay, while Sittee River samples were of a heavier clayey material. Soil characteristics according to Perdue, 1958 [33] and Dudley, 2000 [60], play a very important role in the productivity of Arundo donax, since its vigorous growth is associated with low-gradient and well-drained soils, as evident in the Middlesex plots. The values calculated for Middlesex, confirms the findings of Lambert et al., 2014 [65], whose analyses show that the soil characteristics, moisture and nutrient content strongly influence biomass production of Arundo donax (Figure 5).

Table 1: Soil analysis for the three research sites

Sample Location	Soil Parameters				
	H_2O (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)	pH
Sittee River	33.00	10,762.50	3.065	117	4.390
Middlesex	17.45	5,312.50	4.815	139	6.025
Monkey Rivervv	21.20	6,100.00	6.050	63	7.340

As shown in Figures 3 and 5, highest dry biomass yields were recorded at the Middlesex site, followed by the Sittee River and Monkey River sites. Middlesex had the highest fresh and dry biomass yields on average (15.18 tDM ac-1), although the highest number of stems, 28, 314, were calculated from the Monkey River samples. Middlesex had the next highest abundance with 27,007 stems, followed by Sitte River with a total stem count of 21,562. The average dry matter content for Middlesex, Sittee and Monkey Rivers were 47.4%, 45.5% and 35.2% respectively, under the oven drying method. In comparison, Christou et al., 2001 [61] under Mediterranean climate conditions recorded a maximum of 58% dry matter content, which was air dried rather than oven dried. According to Gunes and Saygin, 1996 [66], air drying may reduce the moisture content of Arundo donax by a further 15%, which may also be influenced by the timing of harvest. For energy generation at the BELCOGEN co-generation facility, a moisture content of approximately 51% is required for use in the furnace. This would result in a higher quantity of dry mass, which in the case of Middlesex with the current 32.02-ton ac-1 of fresh mass,

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would result in approximately 16.3 t DM ac-1 of required dry mass for co-generation.

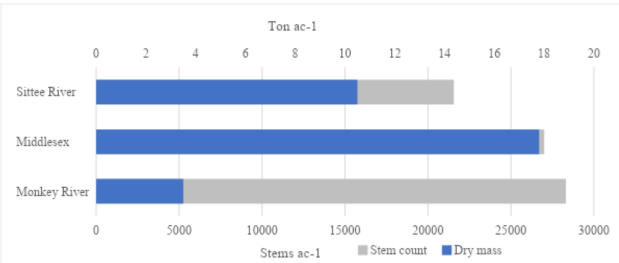

Figure 5: *The number of stems and dry biomass per acre for research sites at Sittee River, Middlesex and Monkey River.*

3.2 ENVIRONMENTAL CONDITIONS

Belize is characterised by two seasons, dry and wet, which lasts from February-May and June-October respectively. Wet season rainfall accounts for approximately 60% of the annual average. Figure 6 shows the average monthly rainfall for the period 1981-2016 at the three sites. Rainfall is an important variable, as it is known to significantly influence the moisture content and dry biomass yield of harvested crops [67,68]. Middlesex monthly rainfall averages approximately 220mm, 40% higher than Monkey and Sittee Rivers. It should also be noted that the rainfall patterns at Monkey and Sittee Rivers were not significantly different during the period 1981-2016. However, it is the differences in soil type and water retention capacity that likely contributed to the noticeable variation in Arundo donax growth and biomass yields. These variables are known to have a significant influence on the level of competition for available nutrients.

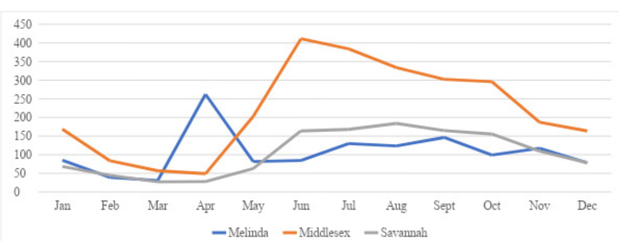

Figure 6: *Monthly average rainfall for the three research sites from 1981-2016*

Rainfall records available for Middlesex for 1990-2016 showed highest precipitation rates occurring during the period March to June. With an increasing trend in both the average Maximum and Minimum air temperature (Figure 7 below), it's suggested that the rate of evaporation would be relatively high, which could cause a decrease in the soil moisture content. Although Arundo donax has been identified as resistant to water stress in dry months [35,69], it has been shown by o Di Nasso, 2013 [70], that increased heat would result in the reduction of biomass yield. While higher rainfall and temperature were recorded at Middlesex, little temperature difference was observed between the Sittee and Monkey River sites. This might also result in relatively similar evaporation rates, with any noticeable variation in soil moisture content likely to be the result of difference in soil type. It was observed that the growth and biomass of Arundo donax are highly dependent on climatic conditions. Since the Sittee and Monkey River sites were not significantly different with respect to climate and biomass yield, it would be reasonable to conclude that it is highly likely that the soil type has the greatest influence on soil moisture and nutrient content.

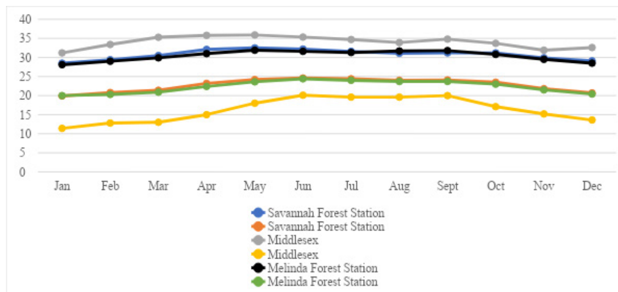

Figure 7: *Monthly average minimum and maximum air temperature within the three research sites for 1990-2016*

3.3 PROPOSED SITE FOR CULTIVATION OF ARUNDO DONAX

In 2016 the CCCCC acquired a 400-acre parcel of land in the Orange Walk District and planned to start the commercial cultivation of Arundo donax, along with the establishment of yield plots for further research on the site as identified in Figure 8 [56]. The area was chosen for its proximity to the BELCOGEN facility at Tower Hill since it would also reduce transportation costs. There are various options considered as potential biomass sources, including Attalea cohune (Cohune Palm) and Acacia mangium (an invasive leguminous species). However, Arundo donax was deemed to be the best option because it can be used entirely in its raw state, requiring no chemical processing and little human input. According to Angelina et al., 2009 [42], growth can be enhanced with the introduction of nitrogen-based nutrients to the soil along with irrigation. In the case of Belize, this nitrogen addition is achieved through runoff and flood waters after heavy rainfall. Should the proposed cultivation area experience a microclimate like that observed at Middlesex, with soil pH ranging between 5 - 8.7, and planting density between 7.5 – 50 stems per m2, it is expected that the volumes of Arundo donax biomass required

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to make processing at BELCOGEN economically viable, can be successfully achieved.

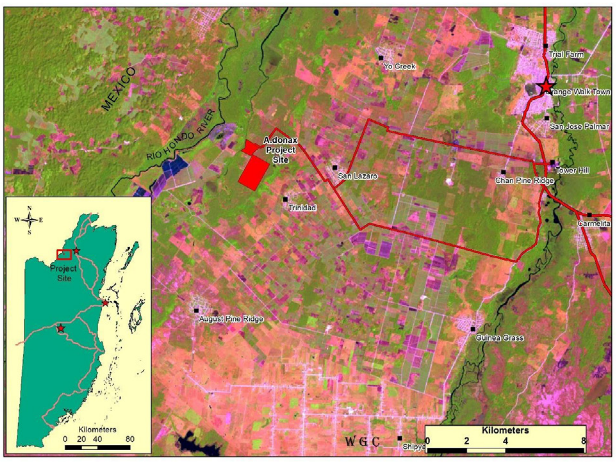

Figure 7: Location of project site within Orange Walk District, Belize. Source: [71]

CONCLUSION 4.0

While constrained by a number of external factors, this study sought to determine the viability of the cultivation of Arundo donax. The study was conducted at a time when the implementation of the proposed CCCCC's Arundo donax project was not yet well advanced. As a result, certain critical outputs from the project were not yet fully realized. For instance, the cost of harvesting, shredding, drying and delivery to the ASR/BSI plant were not yet available, and more important, yield data and compatibility testing parameters were unknown. These data would have contributed significantly to the assessment of the project's economic viability. The present study therefore helped to establish several baselines and generated data on yields, soil quality and water availability. It was also able to identify key climate and environmental requirements that could inform future management practices, when commercial cultivation of Arundo donax for cogeneration commences.

It was observed that of the three plots, Middlesex showed the highest potential for dry biomass production with the lowest soil moisture content. Since Arundo donax could be grown successfully in moderate rainfall conditions with minimum anthropogenic inputs, it represents a cheap and efficient feedstock for producing bioenergy. Further, the research indicates that despite the variability in the biomass yield at the three sites, Arundo donax produces more biomass than sugarcane which is currently used in the cogeneration process. Adequate sugarcane biomass (bagasse) is presently available only during the sugarcane harvest season. Commercial production of Arundo donax would therefore assist BELCOGEN in achieving its target of delivering 13.5MW of electricity to the grid year-round.

Belize is the first country in the Caribbean to substantially invest in scientific investigations into the viability of Arundo donax as a potential fuel source. This CARICOM state has also embarked on an initiative to produce the feedstock on a commercial basis to supply the quantities that would be needed to support sustainable co-generation. The results from this research suggest that Belize possesses appropriate climate conditions, soil quality and available land for the successful production of Arundo donax to meet the requirements of the BELCOGEN facility. As a fuel source, Arundo donax represents a superior alternative to bagasse, the by-product of sugar cane, and is capable of supplementing the latter to ensure adequate feedstock for cogeneration throughout the year.

Research on Arundo donax and its viability, inclusive of its potential for commerciality, is ongoing at the Caribbean Community Climate Change Centre in Belize. There are many potential benefits to be derived from exploring the use of Arundo donax as an energy source. These include (i) the fact that Arundo donax can be grown successfully on non-arable land, and therefore would not pose a threat to crop production and food security (ii) its biomass yield per hectare exceeds that of many fuel crops, including sugar cane (iii) the positive environmental benefit that would be derived from a vastly reduced carbon footprint when compared with hydrocarbon fuels (iii) commercial use of this biofuel would enhance the energy security of Belize, which currently imports >40% of its electricity from neighbouring Mexico and (iv) the substantial foreign exchange savings that would accrue to the country consequent upon the reduced dependency on imported electricity.

RECOMMENDATIONS 5.0

Based on the findings of this study, the following recommendations which are offered as potential contributions to enhancing the ongoing research on and use of Arundo donax as an energy source. The suggestions focus both on areas of research that remain to be investigated, and aspects that need to be better understood and clarified.

It is recommended that analyses on a germplasm level be conducted to properly identify Arundo donax. The close relationship of different varieties of the same genus can be very misleading, particularly with respect to physical identification. Therefore, the use of a germplasm analysis tool to more accurately and efficiently identify the species on a genetic level should be considered. In addition, it is also suggested that a national economic feasibility study on the commercial cultivation of Arundo donax be conducted for Belize. Specifically, a Cost Benefit Analysis (CBA) of cultivating Arundo donax as compared to the current cultivation of sugar cane in relation to farmers' livelihood.

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Further evaluations of the propagation methods (rhizomes, stem cuttings and hydroponically cultivated shoots) and the effects of introducing nutrients particularly Nitrogen (N), phosphorus (P) and potassium (K) to enhance growth and maximize yield are recommended. Such evaluations should give careful consideration to the choice of locations, in order to ensure that the influence of different soil types and conditions can simultaneously evaluated.

During the moisture content testing, it was found that the Arundo donax biomass particles were not consistent with respect to exposed surface area, and as a result, the percentage moisture content calculated varied randomly. Therefore, it is recommended that research be conducted to provide a better understanding of the range of particle sizes that would provide the consistently appropriate moisture content required for efficient burning of the biomass in the cogeneration process. According to Williams et al., 2008 [72], Arundo donax can produce approximately 45 tDMha-1 cellulosic biomass a year, utilising less land and fertilizer, but would require substantial irrigation. In this case, it might be useful to investigate Arundo's tolerance for, and productivity utilizing readily available non-potable water for irrigation. The sources of such water could be wastewater from urbanized areas or from industrial output, absent of pesticides or toxic residue. According to Angelini et al. 2009 [42], Arundo donax appears to be susceptible to few known pests and diseases. Consequently, it is suggested that further exploratory investigations be undertaken to determine the veracity of this claim, and to identify those pathogens that might pose higher risks under future climate scenarios.

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