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Energy, Economic and Environmental Impact of Sugarcane Bagasse in Malaysia.

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Abstract

The rapid development of Malaysia has led to surging energy demands where renewable energy is required to contribute to the energy consumption to replace conventional fossil fuels. Among the option available is sugarcane bagasse. It is vaguely known as an agricultural waste but easily accessible resource mainly in the Northern Part of Malaysia. As part of biomass resource, sugarcane bagasse appears to be a promising alternative as it can be converted to biofuels such as bio-methanol to power fuel cells. Therefore, this paper seeks to provide an overview of the potential of sugarcane bagasse in Malaysia by evaluating the energy, economic and environmental impact of it.

Keywords: *Sugarcane Bagasse; Renewable and Sustainable Energy; Energy; Economic; Environment.*

1. Introduction

Impending World Energy Crisis is calling for an all-out effort to overcome the strain of resources. The abundant energy sources can no longer adapt to the surging demands of the world energy usage. Over consumption of energy emerged as the predominant cause of this issue and the world's energy consumption is expected to again have an enormous growth from 575 quadrillion British thermal units (Btu) in 2015 to 736 quadrillion Btu in 2040, which is an increase of 28% [1]. Delving into the issue further, British Petroleum's Statistical Review of World Energy 2017 pointed that the World's Oil Consumption has hiked from 3984.2 million tonnes to 4418.2 million tonnes from 2006 to 2016, with an average growth rate of 1.5% per annum in 2016. Scientists' concern of the world's dependence on fossil fuels, which holds the biggest share of 86% in the Global Energy Demand started off the examinations and predictions for future trends of fossil fuels [2]. Ultimately, models predict that the world's easily accessible oil would deplete in 2052 [2]. The demise of fossil fuels has certainly provoked the momentum to search for renewable source which would well-suit the urgent needs of global industrialization. In addition, the Paris Agreement adopted shows the world had acknowledged that climate change issues including calamities and catastrophes as grave risks to human civilization. While the carbon budget induced, renewable energy once again appeared as a better alternative in controversial arguments.

Several studies has been made in the area of renewable energies in Malaysia [3-6]. In the Eleventh Malaysia Plan, "Embarking on a Green Growth", the government has set the target of 2,080 MW in renewable energy installed capacity [7]. While the peak demand is projected to reach 17,317 MW from March to May in 2017, the ideal framework is to identify eco-friendly and low-cost alternatives [8]. Despite the large-scale mechanism of electricity generation from hydropower and wind power, to meet the hiking energy demand requirements, renewable resources should all be allotted a representative share. The geographically strategic location of Malaysia along the Straits of Malacca and South China Sea provides a tropical climate throughout the year which makes biomass cogeneration the most potential energy source in Malaysia as the lands are endowed with abundant supply of biomass resources [9, 10].

Biomass energy is an energy derived from living matter which includes agricultural and forestry waste. As one of the leading agricultural commodity producer in the Southeast-Asian Region, palm oil, rubber and wood plantations are easily accessible biomass resources and are all under the supervision of Ministry of Primary Industry and Commodities Malaysia [9, 10]. Whereas in the Northern region of Malaysia, mainly in Perlis, large areas are dedicated to sugarcane plantations [10, 11]. With considerably abundance of palm oil resources, industrial scale production and utilization of biodiesel have had their reasons to be supported. Conversely, Malaysia can attain this amount of agricultural waste of 234 kilotons (2009) of sugarcane bagasse for urgent need for bioenergy [9]. According to Parameswaran [12], sugarcane, official classification *Saccharum officinaru*, belongs to the family Gramineae, commonly found in tropical and subtropical country throughout the world. The fibrous residue of sugarcane after the extraction of juice is known as sugarcane bagasse [8]. It constitutes of about 50% of cellulose, 25% of hemicellulose and 25% of lignin. Being one of the largest cellulosic agro-industrial by-products, sugarcane bagasse can be converted but not limited to vermicompost, bioplastics and biofuel [8]. Therefore, this paper would highlight the energy, economic and environmental impact of sugarcane bagasse hence providing an overview by evaluating each aspect.

2. Energy Impact

A review on electricity generation based on biomass residue in Malaysia [10] shows that, Malaysia produces a total of 700,000 tons of sugarcane from plantations in 2009. In general, 1 ton of sugarcane generates 280 kg of bagasse after extraction, whereas in terms of energy resources, a ton of bagasse (50% wet mill basis) is equivalent to 1.6 barrels of fuel oil. Since the calorific amount of the sugarcane bagasse is estimated to be 14.4 MJ [13], therefore the ideal condition of this amount of sugarcane bagasse would generate 0.421 million Barrel of Oil Equivalent (BOE) per year potential energy [9].

Besides the current initiative of using sugarcane bagasse as boiler fuels in sugar mills, another viable option to utilize this resource is by the production of biofuels, including bio-methanol and bioethanol which are commonly known [14]. From a global perspective, researchers have proven that sugarcane bagasse has the highest potential for bio-methanol production and it is found to have supported 12-25% of the electricity consumed in the western region of the United States, not to mention the fact that it is indicated to be a possible replacement for conventional gasoline and diesel fuel [13]. As for bioethanol, about 60% of the global bioethanol production comes from sugarcane and it is evident to be the most used non-fossil alternative engine fuel due to the wide usage as gasoline substitute in the transportation industry worldwide [15].

According to Raza, Ullah [16], recently, the world has shifted its attention to one of the key elements of the “hydrogen economy”, in which fuel cells are used as clean energy carrier for hydrogen generated from renewable energy resources. As a matter of fact, fuel cells are commonly recognized as “very attractive devices” as it is able to obtain direct electrical energy from the electrochemical reactions of chemical products. It has a high efficiency entitlement due to the absence of Carnot cycle limitations and a lower maintenance cost compared to internal combustion engines [16]. The idea of the production of bio-methanol and bioethanol henceforth running the fuel cells with the biofuels can be quite appealing for Malaysia as they do emerge as promising alternatives for demising fuels.

2.1 Technology in Biofuel Production

2.1.1 Bio-methanol Production

An overview on the Production of Bio-methanol as Potential Renewable Energy [17] states that a myriad of thermochemical processes are proposed for bio-methanol production from biomass residues, including pyrolysis, gasification and combustion. Due to technology progression, several advanced processes are introduced to this field namely biosynthetic, electrolytic and photochemical processes which explicit high efficiency. However, the products are still of lab scale and researches are to be conducted to test on the feasibility for large scale production as these processes are still under the development stage [17].

Shafie, Mahlia [10] reported that, generally, combustion is a widely used and established application for solid biomass. It converts biomass energy into heat energy and after that electrical energy with output production of gases at around 800-1000 °C. Gasification is the thermal breakdown of a biomass particle into gas with existing oxidizing agent such as oxygen, water and carbon dioxide.
In contrast, pyrolysis is the thermal degeneration of the material without oxidation, converting the biomass directly to liquid products [10]. Going further into the matter, pyrolysis technology would well-suit the needs for large scale productions of bio-methanol for diesel engines and gas turbine applications whereas the gasification process, though comparatively cost-effective, would favor the production of gaseous fuel [17]. The combustion process on the other hand makes use of the thermo-chemical process but is only feasible for biomass with moisture content of less than 50% [10].

In terms of yield, the new processes produce small amount of bio-methanol when compared to pyrolysis and gasification process. Contrary to a paper by Shamsul, Kamarudin [17] that shown when compared to the gasification process, pyrolysis displays a higher bio-methanol yield. In brief, the yield of bio-methanol depends on the technology used and the associated kinetic parameters of the conversion process. Numerous factors are taken into consideration as well, including temperature, heating rate and residence time whereas the addition of catalysts would also result in a higher yield efficiency [17].

2.1.2 *Bioethanol Production*

As aforementioned, sugarcane bagasse is a complex matrix of cellulose, hemicellulose and lignin. It is proven that lignocellulosic biomass is essential to meet the desired target of bioethanol production [18]. And this is when sugarcane bagasse comes into place as the ideal raw material in this tropical country. According to the research of Saha, Maharana [18], there are three main stages for lignocellulosic ethanol production:

a) The pretreatment process with ionic liquids such as diluted acid which is commonly used in the commercial industry and is absolutely necessary as the natural structure of lignocellulosic material is extremely recalcitrant to enzymatic hydrolysis [19]. Certain pretreatment methods including using acid and alkaline, steam explosion and ammonium fiber explosion are determined to have high efficiency in bioethanol production [19]. The purpose of the pretreatment process of sugarcane bagasse is to reduce the crystallinity of the cellulose thus enhancing the digestibility of the enzymes [18].
b) The hydrolysis of polysaccharides to monosaccharides such as hexose and/or pentose. Acid hydrolysis of pretreated biomass requires a relatively high temperature and pressure compared to the alternative enzymatic hydrolysis which works at a moderate temperature and pressure, hence requiring a significantly lower energy. It is reported that the reducing sugar yielded was 69.7% under optimum conditions where sugarcane bagasse is pretreated with 1-ethyl-3-methylimidazolium acetate and later on subjected to enzymatic hydrolysis by cellulase [18].
c) The most important step after zymatic saccharification for bioethanol production, which is microbial fermentation. Microbial fermentation converts the hexose sugar mostly glucose containing hydrolysate to ethanol. Basically, the hydrolysis and the fermentation process can be classified into two methods. Simultaneous Saccharification and Fermentation (SSF) reduces end products but employs low enzyme quantity. Conversely, Separate Hydrolysis and Fermentation (SHF) is more ideal as the two processes are done separately. The most commonly used microorganisms for hexose fermentation is *Saccaromyces Cerevisiae* which is able to ferment hexose only, but not pentose [18].

2.2 Fueling the Possibilities

Fuel cells can be categorized into three categories based on the operating temperatures, such as the first category which has an operating temperature below 200 °C, the second category which has an intermediate range of 200-250 °C and the third category which operates at a temperature above 500 °C. For instance, direct methanol fuel cell (DMFC), phosphoric acid fuel cell (PAFC) and the solid oxide fuel cell (SOFC) fall in the first, second and third category respectively [16]. Nevertheless, envisaging biofuels in innovative technologies such as fuel cells would bring the transportation industry to a whole new era.

Based on the paper “Low Temperature Solid Oxide Fuel Cells with Bio alcohol Fuels” [16], the bio-methanol or direct methanol fuel cell (DMFC) is known as “the electrochemist’s dream” and “the ideal fuel cell system” as it produces electric power by direct conversion of bio-methanol. Bio-methanol acts as a favorable fuel for DMFC as it exists in liquid state which allows it to be transported and stored easily without cryogenic containers. Besides that, methanol is easy to manufacture and has a higher energy density than hydrogen, which explicit excellent properties as a biofuel for DMFC [16].

A study from [20] Direct Ethanol Fuel Cells shows that, The Direct Ethanol Fuel Cell (DEFC), is operated based on the solid oxide membrane (electrolyte). The electro-oxidation of ethanol in DEFC produces the electrons thus conducting electricity in a complete circuit. The Membrane Electrode Assembly (MEA) which consists of anode, cathode and membrane connects to current collector is where all the reactions occur [20]. Bioethanol appears to be a feasible fuel in this case as it is carbon neutral, biodegradable and far less toxic than fossil fuels for safety measures [16].

Bioethanol does possess great potential as a sustainable transportation fuel in the future, but it is converted via fermentation of sugar which is presently costly [16]. As a result, bio-methanol emerged as a more promising alternative for biomass sources to generate electricity because bioethanol appears to be a high cost and low yield product [21]. However, Kamarudin, Kamarudin [20] pointed that

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the fuel crossover challenges might bring drawback in the case. Although fuel crossover is a common challenge for all direct alcohol fuel cells, ethanol is well-known of having a lower crossover rate. Ethanol crossover is defined as permeation of ethanol from the anode through the electrolyte membrane to the cathode. When compared to methanol crossover, ethanol crossover affects the cathode performance less severely due to its smaller permeability through the Nafion membrane and its slower electrochemical oxidation kinetics in the platinum or carbon cathode. The negative effects of the crossover include the lowered cathode potential and cathode depolarization, which would result in wasting fuel during the operation, and the possibility of poisoning the cathode catalyst. In brief, modifications are yet to be made to idealize both the biofuels [20].

2.3 Future through the Looking Glass

Like many other countries, Malaysia has taken several initiatives to transform biomass into energy although it is on a smaller scale compared to European counterparts [9]. However, continuous effort are to be made such as the previously launched plan in 2001, A Small Renewable Energy Power (SREP) by the Malaysian authorities to keep tabs on the development of renewable energy as alternatives including sugarcane bagasse thus encouraging the exploration and advancement of technologies in the production and utilization of biomass resources [9]. In fact, introducing a renewable energy feed-in tariff system in Malaysia might as well act as a driving force to develop larger biomass production plants to cope with the rising energy needs [10]. In spite of the low yield of methanol and ethanol in the current study in Malaysia, it is envisioned that future improvements of the process and sample treatments can be achieved by statistical analyses for significant parameters [10]. Apart from sticking to the good old way of disposing sugarcane bagasse which is by using it as boiler fuels to run sugar mills, the potential of sugarcane bagasse being converted to biofuels thus running fuel cells deserves the attention of the researchers in Malaysia. By the year of 2020, it is preponderant for Malaysia to take bold initiatives for one of the most promising alternatives, which is the production of biomass-based resources such as biofuels to meet the energy demands of a developed country [9].

3. Economic Impact

As reported by Landiyanto and Wardaya [22], sugar, is one of the most policy distorted commodities in Southeast Asia. Back in the 1800s, it has been the root cause of numerous problems including adjustments of operations for idealized-profit maximization and evaded prices of sugar-manufactured products, which results in the disposal of the world market in subsidized prices. Sugarcane is known as the main input of the sugar industry in Southeast Asia. The high cost of transportation creates local monopolies and monopsonies and the conflicts between producers and processors are exacerbated due to pricing conflicts which often spill over to political confrontations. However, policies of a country which interplays the domination of sugarcane can be indirect at times, for instance through unilateral trade policy or during the negotiation of regional trade agreements. Theories in economic geography explores the interplay between increasing return at plant levels, market size and geographical distance. A common result is an inverted U-shaped relationship between concentration of industrial production and transportation cost. World Economic Development clusters on limited geographical space, in the case of sugarcane industry, Malaysia is characterized by high levels of sugarcane production [22]. However, in the representative of multitude of potential settings for developing countries, sugarcane bagasse was not selected in the matrix of selected countries and feedstock combinations for Malaysia as a few contributing factors were integrated, namely the level of input intensity, the level of mechanization and the presence of tillage [23].

3.1 Economic Consideration: Lignocellulosic Biomass

Goh, Tan [24] showed interesting ideas about the status, perspectives and challenges of lignocellulosic biomass in Malaysia. As previously stated, sugarcane bagasse is a form of an easily-accessible and low-cost lignocellulosic biomass feedstock. However, in developing countries like Malaysia, there is no fixed market value for lignocellulosic biomass as the cost is fully dependent on the location delivered. Hence a solution was brought up, which is to integrate the biorefineries with lignocellulosic processing units. Yet, the biorefineries are not widely and commercially viable due to the high capital and operating costs [24].

Likewise, technology obstacles would undeniably be a contributing factor in this issue. As aforesaid, the pretreatment stage is where the hemicellulose is solubilized. Although there is a myriad of pretreatment processes to choose from, depreciation of capital has still emerged as one of the largest cost components. The predominant factor which stops the players to invest in this field, is the long period needed to recoup the capital. An example depicted is that $0.5 billion USD would only suit the construction of a multi-product plant with a production rate of 1000 to 2000 tons per day. Efforts were made to attract investors including a strategy introduced, called the "local ownership" concept [24].

Data has shown a sizable investment around $50-100 million USD is needed to fund the basic infrastructure for biomass harvesting, collecting, storing and transporting for supplying 1 million of dry ton per year to biorefineries, which is still negligible. Furthermore, equipments and operation cost would add on to extra cost as lignocellulose is not a readily accessible carbon source, not to mention the enzymatic hydrolysis process which would also be a considerable cost component. Additionally, engineering constraints are still present in this case which hinders the large-scale commercial use of lignocellulosic biomass due to relatively expensive cellulase but fortunately the National Renewable Energy Laboratory (NREL) has made steady progress of this issue [24].

In short, further solutions are yet to be explored including the contribution of the agricultural organizations and government departments such as the Ministry of Plantations, Industries and Commodities to enhance the feasibility of sugarcane bagasse in Malaysia [24].

4. Environmental Impact

As illustrated in "A Safe Operating Space for Humanity" [25], the Earth has been unusually stable for the past 10,000 years, the state is known to geologists as the Holocene. Ever since the Industrial Revolution, the Anthropocene has emerged as a whole new era, in which human activities became the main drive of environmental change [25]. The peak of human civilization threatens the environmental state of Holocene which can consequent in detrimental annihilation and destructions. In the 15th Conference of Parties in Copenhagen in the climate change mitigation agenda, Malaysia has volunteered to contribute by reducing the emissions intensity of gross domestic products [26]. Therefore, in order to reverse environmental degradation, three fundamentals are to be conducted, such as restoration of carbon, maintaining sustainable production and consumption and biorefinery for a circular economy to ensure that there is no negative impact to the ecosystem and environment across value chains [26].

As reported by Petinrin and Shaaban [27], nowadays, the load demands in the distribution system has brought biomass and biofuels another step closer to substitute the depleting fossil fuels due to their environmental-friendly characteristics. Being one of the potential renewable energy, widespread biomass cogeneration would reduce the emission of greenhouse gases (GHG). In 2002, a biomass power plant was commissioned in Malaysia, jointly funded by both private and government sectors namely the Global Environmental Facility and the United Nations Development Program to reduce the carbon dioxide emissions [27]. Wider range of agricultural wastes can be adopted to accelerate biomass power cogeneration in Malaysia and the outcomes would in turn favor the environment much more.

4.1 Roadmap to Green Growth

Green energy is defined as energy generated from renewable resources which are environmental-friendly [28]. Hydropower, biomass, geothermal and wind power are considered forms of green energy which leads to green power marketing around the world.

A study by Demirbas [29] shown that advancement in cogenerative conversion technology has been found to be useful in recovering the heat present in biomass fuel, namely the biomass gasification and wind turbine combined cycle. For instance, cogeneration is proposed as an idea to prevent pollution. Cogenerators make use of excess heat to enhance the efficiency by up to 80% with respect to the traditional systems of 33-38%. It is designed to recapture and process heat separately to generate extra electricity, which can save up to 15-35% of fuel, thus reducing heat released to the environment at the same time [29].

According to "Social and Environmental Impact of the Sugarcane Industry" [30], Instead of the traditional way of burning the sugarcane straws which would cause particulate matter and smoke risk, converting sugarcane to biofuels such as bio-alcohol would be a standout. In particular, studies have indicated that the total emission of volatile compounds and the exhaust gas possess less potential to form photochemical smog than oil. In addition, when comparing between the combustion of biomass fuels and fossil fuels, biofuels produce significantly less nitrogen oxides and sulphur dioxide where this small change can heavily impact the environment [30].

Furthermore, the utilization of Distributed Generation (DG) technologies especially in biomass gasifiers provides better option with significant carbon dioxide emission mitigation potential when running on a net-metering scheme which allows excess kilowatt-hours (kWh) to be sold back to the utility at retail tariff levels [31]. From another perspective, the use of pesticides and fertilizers of sugarcane crops are found to be less than other biomass resources including corn and soybean crops and the use of fungicides is virtually zero, which indicates that the possibility of underground water contamination is much more lower [29].

However, what worth taking note is that a safe method is required for the conversion of sugarcane to its bagasse form as there are risks of causing bagassosis, an interstitial lung disease [32]. Improper disposals from this type of agricultural waste are reported to have cause acute and chronic effect to eyes and allergy responses as well, which are chronic defects to human health [32].

5. Conclusion

A statement is proposed repetitively by scholars and researchers: "Malaysia is a blessed country with excellent geographical location and tropical climate which allow access to countless resources." And there the question arises, is Malaysia capable of full utilizing what it is gifted? It is undeniable that in this decade the government has included the feasibility of renewable energy in current and future plans. A few notable resources which draws the most attention includes hydropower where dams are under high surveillance and supervision. And the oil palm sector, which takes up a huge percentage in the gross income of the country. The researches for sugarcane feasibility are still limited and not much information is released to the public. Laypersons in particular would not expect that sugarcane bagasse possess such great potential in energy generation and would do such little impact to the environment. Thus, it is the reason where investor would not pool their resources to make bold investments in this sector. Malaysia is still a developing country compared to Brazil which is rapidly industrialized and developed. Due to lacks of technology and expertise in this field to convert sugarcane bagasse into biofuels, and the applications in automobile and portable devices are still limited. Not to mention that the sugarcane plantations are only focused in the Northern part of Malaysia compared to the abundance of sugarcane resources in Brazil. It is agreeable and wise for the government to put in more effort in other appealing and high potential sectors while waiting for the chance to strike. Perhaps, if the present resources could not suit the energy demand, that is when it would be a safe bet to consider utilizing this biomass resource, sugarcane bagasse.

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