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Feasibility Study on Biomass Bamboo Renewable Energy in Malaysia, Indonesia, Vietnam and Japan

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Bamboo has become a new trend or focus point as a source of biomass energy in which its proper application is believed to generate the electricity with near-zero waste. ASEAN countries especially have an abundant amount of bamboo that has been use for decades in various applications through their civilization. This study aims to determine the feasibility of bamboo as a renewable energy resource in Malaysia, Indonesia, Vietnam and Japan. This paper reviews general biomass bamboo, availability, and methods of technology in the respective countries based on the review of publication papers and country reports. This fast-growing crop is identical for biomass production as it rapidly self-propagates. Bamboo requires minimum maintenance to grow and is always accessible to be harvested. The woody nature of the tropical bamboo stem contributes to its high calorific value in the form of energy. It was found that Indonesia had become a leading country in generating renewable energy via biomass bamboo through a power plant with a capacity of 700 kW off-grid in Mentawai, Japan with a power generation capacity of 995 kW and Malaysia with 4 MW, will be commercialised by 2023 and 2022. In conclusion, biomass bamboo has great potential for renewable energy generation within these countries. This has consequently contributed to increase in the value of bamboos while positively impacting the socioeconomic stance of the community.

1. Introduction

ASEAN's annual growth rate in electricity demand has been among the fastest in the world, at 6 % on average (IEA, 2019). A total of 45 M people in the ASEAN region still do not have access to electricity, especially the population in remote and rural areas. This situation has generated concern over the power shortage possibilities in the future if the electricity demand were to exceed its available supply. The ASEAN region's biomass resources are currently relatively abundant and underutilized. According to Goryunov et al. (2016) the main sources of biomass particularly come from residues of the world plant, animal waste, agriculture and forestry. These resources are sustainable and environmentally conscious in the production of energy. The available biomass energy can be converted into several particular types of energy such as electricity, gas, thermal and charcoal (biochar) through the existing biomass technologies.

As of 2019, Malaysia's renewable energy generation made up 7 % of the total energy generation. Biomass contributed to 2 % of this value. The national target is to achieve 20 % of renewable energy in the capacity mix by 2025 (Energy Commission, 2019). Main resource of biomass energy in Malaysia are from the oil palm, empty fruit bunches, palm kernel shells, sugarcane, and rice husk. Indonesia's national new and renewable energy mix target is aimed at achieving at least 23 % by 2025 and 31 % by 2050. As of 2018, the power plant's installed capacity for renewable energy is at 14 %(Secretary General of the National Energy Council, 2019). Based on

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the National Energy Policy, biomass will share 10 % of the national energy mix by 2025. Indonesia's options for biomass resources could be derived from the forestry and agricultural industries, including products from rubber, wood, logging residues, sawn timber residues, plywood residues, sugar residues, palm oil residues and bamboo (Petuah, 2016). Vietnam has achieved more than 25 % of its renewable energy in 2020. Renewable energy is expected to dominate the total power generation mix by 2030 making up 32 % of electricity supply (Ha, 2021). Vietnam has set the target of power production from biomass energy to constitute 1.2 % in 2025 and 2.1 % in 2030 of the country's total energy mix (GIZ, 2020). The available biomass resources in Vietnam include rice straw, rice husks, bagasse, coffee husk, coir and wood residues. Japan aims for its country's renewable energy generation mix to be between 22 % and 24 % in 2030 as outlined in the 5th Strategic Energy Plan (METI, 2018). Their projection for the 2030 energy mix includes a biomass share of 4 % with generation capacity of 32.8 TWh (METI, 2015). The biomass resources available in Japan are wood chips and agricultural crops.
Researchers have studied the potential feedstock for electrical generation from various types of biomass. Bioenergy in Indonesia is primarily derived from oil palm, which has been associated to environmental and social issues (Sharma et al., 2018). Malaysia is still facing major issues on biomass supplies (Eker and Spinelli, 2018). Malaysia's research on biomass is mainly focused on palm oil residues such as palm kernel shell and empty fruit bunch (Teh et al., 2021). Present research show that studies on agricultural by-products in Vietnam such as rice straw, rice husk, sugarcane bagasse and sugarcane trash for biomass energy is being conducted (Benova et al., 2021). Pambudi et al. (2017) explained that there are currently several challenges for the development of biomass energy in Japan due to its limited domestic natural resources. Although ASEAN and Japan have many bamboo resources, there are very few studies addressing bamboo as a source of biomass energy. This study will address the feasibility gap of using bamboo as a potential renewable energy source in Malaysia, Indonesia, Vietnam, and Japan. The objective of this study was to determine the potential of bamboo as a renewable energy resource. The bamboo biomass generation is also addressed to the respective ASEAN countries and Japan based on the review of publication papers and country reports. This data will support and assist these countries for future direction on bamboo utilization as biomass energy.

2. Bamboo characteristics of biomass potential source in respective ASEAN countries

Bamboo is categorised as part of the grass family and it grows naturally throughout Asia, Africa and many parts of South America. Bamboo is regarded as one of the most sustainable renewable resources due to its usefulness and speed of growth. According to Truong and Le (2014) bamboo has a woody stem or culm despite being a type of grass that can reach a height of 15 to 40 m tall. The largest known species of bamboo is the *Dendrocalamus giganteus*, with a life span of 30 to 60 y. Bamboo grows fasts and meet maturity in just 3 to 4 y compared to traditional timber, which takes up 15 times longer before it can be harvested. The fact that bamboos rapidly self-propagate after harvesting, introduce a possibility for bamboo forests to quickly spring up, preventing deforestation and soil erosion. Bamboo has also had an intensive application for centuries in construction, textile, furniture, handicrafts, and the food industry. This plant is seen to have a positive impact on bioenergy. The value of bamboo however is largely underestimated despite its wide application and potential commercialization. Bamboo has desirable fuel characteristics of low ash content, high volatile matter, and high heat value (HHV). Table 1 summarized the comparison of bamboo characteristics with other biomass resource and coal. Bamboo has a high calorific value, almost equivalent to wood with low content of nitrogen and sulphur (Purbasari et al., 2016).

Table 1: Comparison of bamboo characteristics with other biomass resource and coal.

Biomass	Proximate analysis (mass %)				Ultimate analysis (mass %)					HHV	Reference
	M	VM	FC	A	C	H	O	N	S		
Bamboo	7.1-10.2	72.0-80.0	10.8-18.4	1.1-2.7	48.2-50.9	6.0-6.4	42.3-45.2	0.24-0.46	0.05-0.07	18.2-18.8	(Park et al., 2019)
Palm Kernel Shell	8.19	70.45	18.89	2.47	48.25	6.41	42.69	0.15	0.03	19.82	(Waluyo etal., 2018)
Sugarcane bagasse	6.70	91.70	8.30	10.30	51.90	6.90	40.50	0.40	0.50	16.60	(Aboyade et al., 2013)
Bituminous Coal	5.19	31.87	58.16	4.78	75.39	4.64	12.08	1.11	0.53	25.88	(Geng et al., 2016)

The chemical components from bamboos originating from different locations and physiological ages may differ in contents, as well as within an individual bamboo culm. Figure 1 indicates the availability of bamboo resource in Malaysia, Indonesia, Vietnam and Japan.

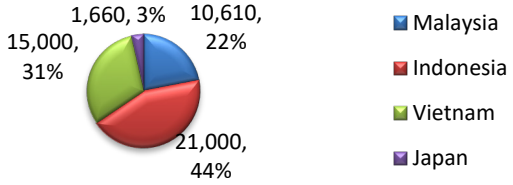

Figure 1: Bamboo resource area, *km² (INBAR, 2019)*

According to the Forestry Department of Peninsular Malaysia, the country is home to 70 unique bamboo species. Peninsular Malaysia's bamboo cultivation of 3,290 km² represents 31 % of the total available land (Primary Industries Ministry, 2018). In 2015, Indonesia reported to have a total of 160 bamboo species (INBAR, n.d.). Its bamboo forests cover around 7,000 km² in which 14,000 km² are from farming property. The sum up of bamboo covers in Indonesia region is around 21,000 km². Vietnam is estimated to have around 216 bamboo species. There are 15,000 km² of pure and mixed bamboo forests in Vietnam, accounting for over 10 % of the country's total forest area (INBAR, 2019). Japan has around 1,660 km² in bamboo forests to be utilized (Nakanishi, 2019). Lignocellulosic biomass is considered as a renewable raw material with high energy potential (Ullah et al., 2015). Bamboo biomass is a potential bioenergy source as it is composed of lignocellulosic material (Poudel, 2020).

3. Biomass bamboo generation in respective ASEAN countries

The countries in the ASEAN region have started to acknowledge the biomass energy production from bamboo resources. Table 2 shows the existing project of biomass bamboo pilot plants in Malaysia, Indonesia, Vietnam and Japan.

Table 2: Bamboo biomass pilot plant in Malaysia, Indonesia, Vietnam and Japan

Country	Location	Capacity (kW)	Technology	Feed-in Tariff (USD/kWh)	Commercial Operating Date	Reference
Malaysia	Gurun, Kedah	4,000	Gasification	*0.091	2022	(Pakar, 2020)
Indonesia	Mentawai, West Sumatera	700	Gasification	**0.15	2018	(CPI, 2021)
Vietnam	Lam Dong	na	na	Na	na	(Truong and Le, 2014)
Japan	Nankan town, Kumamoto	995 (power) 6,795 (thermal)	Cogeneration	Na	2023	(Nakanishi, 2019)

na = not available, *on-grid, **off-grid

3.1 Malaysia

Malaysia has introduced a bamboo biomass power plant located in the state of Kedah via a partnership company known as Pakar B2E Sdn. Bhd. The power plant is projected to have 4 MW of installed capacity with an approved Feed-in Tariff rate of 0.091 USD/kWh and effective period of 21 y from the Malaysia's Sustainable Energy Development Authority (SEDA) (Pakar, 2020). The power plant is still in the preparation state and is expected to begin operating on March 2022. This first biomass power plant using bamboo resources in Malaysia is going to benefit thousands of people, especially in rural communities. This plant will create new job opportunities and support the local bamboo farmers. The plant will utilize approximately 4,000 metric t of bamboo in a month supplied by the farmers and village people through harvesting the untapped wild bamboo in the region. This biomass bamboo power plant is targeted to help the rural development in Kedah.

3.2 Indonesia

Indonesia has become the first country in Asia Pacific to successfully develop a bamboo-based biomass power plant. The project is located in the remote area of Siberut Island in Mentawai, West Sumatra encompassing three villages which are Madobag Village, Matotoan Village in South Siberut District and Saliguma Village in Central Siberut District. The three biomass power plants were designed to generate a total of 700 kW of electricity which consists of 6 units of 100 kW system and two units of 50 kW system that will supply to 1,250 households. It also generates 450 jobs for the operation and maintenance of the plants. PLN purchases all of the project's electricity generated under a 20 y Power Purchase Agreement (PPA) at a regulated price of 0.15

USD/kWh. PLN then sells the electricity purchased from the project to the community at its National Electricity Rate (TDL) of 0.031 USD/kWh (CPI and CIFOR, 2019). With an investment of 12 M USD from a foreign donor, this power plant has become a source of income for the local community and has improved the regional economy. It is also perceived to remove 3,000 t CO_2e/y from carbon sequestration and emission avoidance by means of this new bamboo planting. With 70 % of cost efficiency, the power plant can contribute to the increase of Indonesia's national electrification rate in achieving renewable energy mix target of at least 23 % by 2025. Yoesgiantoro et al. (2019) studied that the cumulative net cash flow generated by the biomass bamboo power plant in Mentawai is expected to be around 10 M USD in the 30th y with a payback period of 16 y. Recognizing the potential of bamboo resource for beneficial effects, the Indonesian government intends to increase the capacity of bamboo biomass energy to 500 MW (GGGI, 2019). After a few years of operation, the performance of the plants has been decreasing. The plants could not operate continuously due to frequent breakdowns (Febrianti, 2020). The plants now generate electricity below its design capacity. The bamboo-derived raw materials were often replaced by other less sustainable alternatives such as fossil fuels. Many villagers supplying the bamboos complained that the selling price is not economically viable (Jacques, 2021).

3.3 Vietnam

At an industrial scale, the bamboo waste residues contributed by floor manufacturing facilities in Vietnam are ranging around 50 % to 70 % of the total bamboo processed (PI, 2006). The waste is used as a primary energy source to heat boilers and provide process heat to the factory. Bamboo is considered to have significant potential for integrated renewable energy and heat production at these factories (NL Agency, 2012). Vietnam's biomass bamboo power plant initial plan has been proposed in Lam Dong province with a project called "Bio-energy source from sustainable bamboo". The project is under Bamboo Matter Co., Ltd, Biocandeo Company (Netherlands). The International University-Vietnam National University (IU-VNU) is expected to produce over 10,000 t of biomass bamboo (Truong and Le, 2014). This project will cover a total of 200 km^2 of bamboo forests in the districts of Di Linh, Dam Rong and Bam Lam. The goal is to produce biomass energy from sustainable bamboo grown in these forest areas, increasing the value of local bamboo and attempting to maintain and preserve natural forest areas. This creates job opportunities for the local community. The project status is unascertained as it has not been updated to date. Vietnam from its well-known agricultural industry has a large potential for bamboo biomass. The local community could greatly benefit from the implementation of this project.

3.4 Japan

Japan has completed its biomass bamboo power plant construction by Bamboo Energy Co., Ltd. and began operating in 2019 in the town of Nankan, Kumamoto Prefecture. This project falls under the New Energy and Industrial Technology Development Organization (NEDO). This plant was also the first organic Rankine cycle (ORC) cogeneration system for heat and electric power generation using bamboo resources. It is expected to be commercialized in 2023(Nakanishi, 2019). The system utilizes 8,750 t/y of bamboo, with generated electricity of 995 kW and thermal output of 6,795 kW(NEDO, 2019). This plant is expected to promote the holistic usage of bamboo resources and increase their value. In return, this should alleviate the regional problem of unmanaged and overgrown bamboo forests. The project also intends to make the most of the region's biomass resources and establish biomass energy generation that would boost local economic conditions.

4. Feasibility of technology

In ASEAN countries there are two main methods of thermo-chemical processes in converting biomass into energy, namely combustion and gasification. More than 90 % of the world's main energy supply is produced by direct combustion (Chin et al., 2017). Direct combustion is a method of processing biomass that involves burning it in the open air or in the presence of excess air. This process is carried out at a temperature ranging from 800 °C to 1,000 °C inside a furnace, steam turbine, or boiler. It is suitable for all types of biomass which have low moisture content, ideally less than 50 %. Direct combustion is often applied at an industrial scale in the form of co-generation to produce electricity and thermal power (Truong and Le, 2014). This method of using cogeneration for bamboo biomass power plant is applied in Japan. Bamboo production through the cogeneration system resulted in ash melts and clinker formation that damage the furnace. To address this issue, the plant used 30 % of bamboo and 70 % of cedar bark to increase the melting point of the ash. Direct combustion technology is more difficult to operate and less efficient than gasification equipment. Despite this weakness, it is also more mature and widely used due to a lower biomass quality requirement (Guillaume and Bussy, 2012). Gasifiers refine biomass feedstocks into a clean-burning gaseous fuel which produces gas that is compatible with internal combustion engines. The system converts biomass feedstock into producer gas using the processes of gasification. This is done in four stages known as drying, pyrolysis, combustion and reduction. One of the critical aspects of gasification operations is to reach a sufficient quality of syngas and low

temperatures to avoid potential harm to the engine. This requires management of particles and tars. This method is used by the Malaysian and Indonesian biomass bamboo power plant. The gas yields and carbon conversion efficiencies acquired from bamboo gasification were identical to those obtained from other biomass materials, but higher than cellulose (Wongsiriamnuay et al., 2013). Both technologies are widely adopted in the ASEAN region for biomass energy generation with regards to its ability to reduce greenhouse gas (GHG) levels. Further research and improvement are required to make the best use of the technologies for bamboo biomass plant.

5. Conclusions

The feasibility of biomass bamboo renewable energy for Malaysia, Indonesia, Vietnam and Japan has been discussed in this study. The sustainability of bamboo resources have a significant impact on the energy-economy and power generation as a solution for energy shortages and to support the rural electrification. Indonesia is working on meeting their electricity needs through biomass bamboo energy. Despite some hurdles, Indonesia has demonstrated the technological viability of a full-sized bamboo biomass power plant in Mentawai. Upon the successful implementation of this biomass bamboo power plant in providing full access to electricity in rural area, the Indonesia government intends to increase the capacity to 500 MW. Followed by research and pilot plants of bamboo biomass in Malaysia with 4 MW and Japan with 995 kW. Based on the result, biomass bamboo is a great potential as a renewable energy source for these countries. It has and will contribute to the increase of bamboo value, lower the carbon footprint and have a positive impact towards the socioeconomic of the community. As it is a new bioenergy resource, more research towards bamboo characteristics, suitable technology, optimization of bamboo utilization will be carried out through pilot plant in laboratory and simulation.

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