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Optimum Location of Biomass Waste Residue Power Plant in Northern Region: Economic and Environmental Assessment

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ABSTRACT

Biomass waste create huge potential in power generation. However, the critical parameter that needs to be considered in the first place is the optimum location of the plant. Hence, the aim of this study is to establish a spatial biomass resource optimisation framework so as to create a guideline for Malaysia's sustainable energy and environmental management. The most potential biomass resources that are available in the northern region of Malaysia are chosen, namely rice straw, rice husk, garden waste, corn residue, sugarcane bagasse, and coconut residue. The life cycle greenhouse gas emissions are varied from 0.02 kg/kWh to 6400 kg/kWh and life cycle cost varied from RM 0.09/kWh up to RM 25.37/kWh. The optimised electricity generation obtained 1.61 MW for the total power generation. The optimum design of power plant used garden waste as fuel, followed by rice straw. Baling has the potential to generate the optimum capacity with 0.6 MW of electricity output by using garden waste as the main fuel. It means that the maximum power of electricity could be generated at each zone from 0.05 MW up to 0.6 MW. Hopefully, this result provide the guideline for decision maker to implement the renewable energy in the future.

Keywords: Optimum Location, Biomass Waste, Power Plant, Malaysia
JEL Classifications: Q40; R11

1. INTRODUCTION

In the development of a biomass waste residue power plant, the main parameter that needs to be considered in the first place is the optimum location of the plant. The undetermined issue relating to biomass resources is the burning of crop residues or leftover biomass by farmers after harvesting that harms the environment. The high transportation cost is one of the reasons farmers opt to burn crop residues as a low-cost approach to eliminate them (Ghani et al., 2018). In developing countries, a majority of them manage residues by burning leftovers. Burning is among the traditional ways in waste management that causes harm to the environment. Biomass power generation supply chain is more difficult in comparison to the supply chains of solar and wind power generation. Biomass energy involves a complex process considering the mass quantity, Unwieldly form, relatively low energy density, and wide distribution of biomass resources (Liu et al., 2015). Hence, extra attention is needed to overcome all these problems.

Currently, issues related to energy efficiency and optimisation have begun to raise concerns in the design and development of biomass power plants (Mao et al., 2018). According to this paper (Jeong and Ramírez-Gómez, 2018), selecting the optimum biomass plant location is a major issue as a result of the geographical and spatial distribution of biomass feedstocks. Most biomass supply studies prefer to be conducted in the context of locality. Hence, the research in (Bojic et al., 2018) focused on the selection of an optimum lignocellulosic bioethanol plant, which was vital in decreasing the costs of supply and greenhouse gas (GHG) emissions in the Serbian context.

The logistics for storage and transportation purposes is a major concern regarding the utilisation of biomass in power plants.

Another vital concern is the selection of feedstocks. The parameters chosen to develop the optimum design of power plant are generated from the research in (Perpiña et al., 2013). The process of selecting the optimum location and designing a biomass combustion system greatly relies on the fuel type, costs, environmental law, equipment performance, and the required capacity and energy (Gebreegziabher et al., 2014). According to the study in (Zhao and Li, 2016), the environment and cost components related to the generation of biomass power are the main parameters that should be considered when designing biomass power plants. In addition, other parameters to be considered in order to meet the requirements of power plants and minimise cost and environmental impact include the locality and design of power plants, choice of biomass type, and transportation routes (Martínez-Guido et al., 2018). These papers also determined the optimisation of the entire supply chain structure by minimising the overall cost and GHG emissions (Idris et al., 2018). As a conclusion, the optimum design of biomass power plant is mostly influenced by cost and environmental factors.

1.1. Deterministic Concept in Designing Biomass Power Plant

In order to resolve the above mentioned issues, a spatial optimisation framework is modelled to identify the optimum location of biomass power plant, by minimising the total cost and total GHG emission (Idris et al., 2018). The design of biomass power plant is formed on the basis of an analytical model, whereby this model includes the geographical and social factors that are mostly challenging to be outlined (D'Ovidio and Pagano, 2009).

The main objective of this study is to establish a spatial biomass resource optimisation framework so as to create a guideline for Malaysia's sustainable energy and environmental management. Focusing on Kedah as the case study for this research, a few specific objectives have been delineated as follows.

The proposed model aims to achieve the optimum electricity output by minimising the total life cycle costing (LCC) and total life cycle of GHG emission of the power generation system. The optimisation model proposed in this study focuses on minimising the total cost of power generation and minimising the life cycle of GHG emission for a particular amount of electricity produced from biomass resources. The model aims to minimise the total cost and emission of the system, and at the same time, identify the optimum location of power plant and facility, optimum biomass blending, optimum fuel blend, and optimum carbon emission scheme. In this present research, various agricultural residues are taken into consideration, namely rice straw, corn residue, rice husk, garden waste, coconut residue, and sugarcane residue.

2. METHODOLOGY

The utilisation of various technologies with distinctive costs and capabilities has helped the transformation of biomass residues to generate electricity. Therefore, the possible amount of electricity generated is dependent upon the type of technology employed. The objective of this study is to establish a model to identify the total GHG emission and total cost in order to produce the most cost-effective amount of electricity with the utilisation of available biomass resources. Figure 1 displays the system boundary employed in this study. Steps 1 and 2 have been carried out in the previous study.

- Step 1: The most potential biomass resources that are available in the northern region of Malaysia are identified. Six types of feedstock are chosen, namely rice straw, rice husk, garden waste, corn residue, sugarcane bagasse, and coconut residue.
- Step 2: The system boundary for each biomass crop is determined, starting from production, collection, lorry transportation, storage, truck transportation, and power plant. The LCC and life cycle assessment will go through each process inside the system boundary for each biomass crop.
- Step 3: The optimisation of the location is determined with the optimised value of electricity generation and the variety of biomass feedstocks.

2.1. Resource Availability Estimation

The optimum locality to build a biomass power plant in the northern region of Malaysia is determined purely by looking at the highly potential biomass resources available. In accordance to this, the district of Kuala Muda was chosen. Figure 2 shows the available biomass resources in Kedah for 2015.

2.2. Optimisation Design

In order to develop a cost model for the collection and transportation processes of rice straw, the following are considered:

a. In the summation, it is assumed that every biomass resource location is a circular land
b. Straw resources are equally distributed within a particular collection boundary as they are gathered in main collection stations

Figure 1: System boundary applied in this study

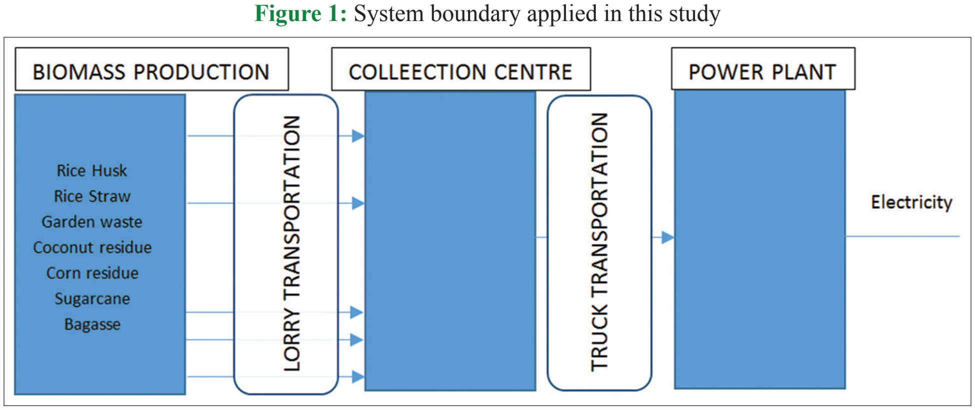
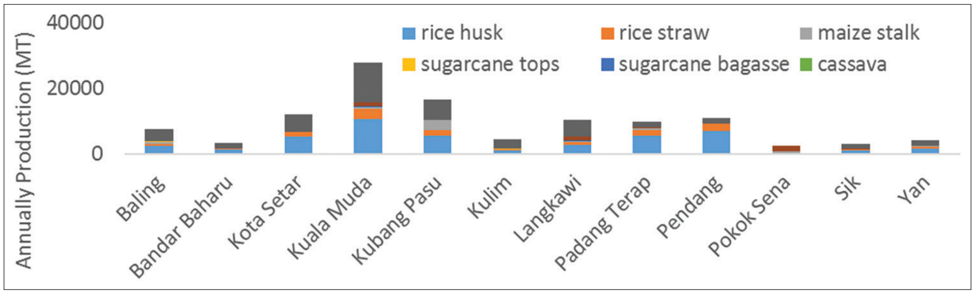


Table 1: Life cycle of greenhouse gas emission and cost for each available biomass resource

Biomass resources	Rice straw	Corn residue	Rice husk	Sugarcane top	Garden waste	Sugarcane bagasse	Coconut residue
Emission (kg/kWh)	6400.04	7.34	3207.22	0.02	1468.88	1.91	1082.35
Cost (RM/kWh)	25.37	2.20	17.96	16.10	0.09	9.36	12.46

Figure 2: Available biomass resources in Kedah (2015)



c. The variations of straw have not been taken into consideration
d. In every main collection station, acquisitions are made within a radius, Ri
e. Transportation cost has a linear correlation with distance.

In creating an optimum design of biomass power plant, Equation (1) is used.

$$P_{OPT} = min \sum_{n=1}^{n=k} (C_T)(E_T) \tag{1}$$

Where; C_T is equivalent to the total LCC and E_T is equivalent to the life cycle of GHG emissions. The optimum design consists of the following components:

a) Decision variables: The power plant's capacity for each zone. In this case, $P_1 \ldots P_k$. The generation of electricity is in kWh
b) Objective function: The objective is to minimise the LCC C_T and the life cycle of GHG emissions E_T
c) Constraints: The limitation of the design is the availability of biomass resources for each zone.

Figure 3: Life cycle of greenhouse gas emissions for each process

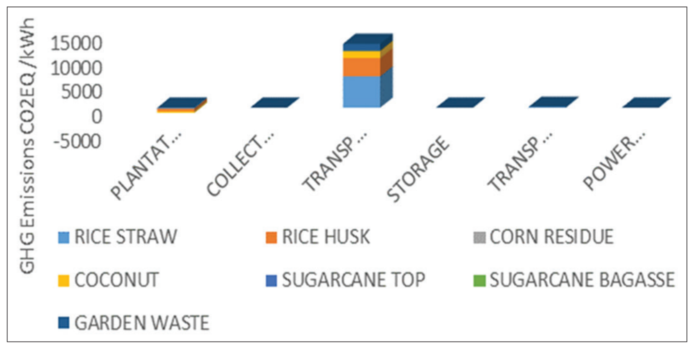


Figure 4: Life cycle cost for each crop process

3. RESULTS AND DISCUSSION

Table 1 indicate the life cycle of GHG emission and cost for each available biomass resource. Rice straw emitted the highest GHG emission throughout the process of electricity generation, which was 6,400 kg/kWh. The LCC for garden waste was the lowest for electricity generation, which was RM0.09/kWh. According to the study in (Stich et al., 2017), there are different costs of power generation, ranging from <40 USD/MWh to >200 USD/MWh. On the other hand, the simulation result of the study conducted in Egypt indicated that the cost of the proposed rice straw power plants ranged between 10.55 ¢/kWh to 6.33 ¢/kWh (Abdelhady et al., 2018). The most contribution process toward GHG emission are from transportation process, while plantation process is the highest contribution toward cost production. This result can be refer to the Figures 3 and 4, that show the life cycle of GHG emissions and life cycle cost for each process. The life cycle of GHG emission for rice straw was higher due to the transportation process. Therefore, local criteria such as handling of crops, locality of power plant, and fertilisation practices need to be further evaluated so as to reduce environmental impacts. A previous study showed that the life cycle of GHG emission ranged from 1,000 g/kWh to 5,000 g/kWh for different types of biomass resource.

Figures 5 and 6 displays the life cycle of GHG emissions and cost for each crop process in electricity generation in Kedah. It is indicated that the most critical GHG emission came from transportation, with the most contribution from rice straw, rice husk, and garden waste. Meanwhile for costing, the top three processes affected were plantation process, power generation process, and collection process.

Table 2 indicates the allocation of biomass power plants for optimised power generation. Optimum power plants could be achieved by using rice straw as fuel in Kota Setar, Kuala Muda, and Pendang. Meanwhile, Kubang Pasu could generate the optimum electricity output using corn residue. Table 2 denotes the amount of electricity generated for different biomass resources for the optimum output zone. All indicated zones will

Table 2: Allocation of biomass power plants for optimised electricity generation

Zone	Electricity generation (kWh)					
	Rice straw	Corn residue	Rice husk	Sugarcane top	Garden waste	Coconut residue
Baling				10910.5	5491044.5	46369.7
Kota Setar	2683001.7					
Kuala Muda	323744.4		89966.8		1105131.9	498215.8
Kubang Pasu		98702.7				
Pendang	2836749.9					
Yan					935683.9	
Total	5843495.9	98702.7	89966.8	10910.5	7531860.4	544585.5

Figure 5: Life cycle cost for each crop process

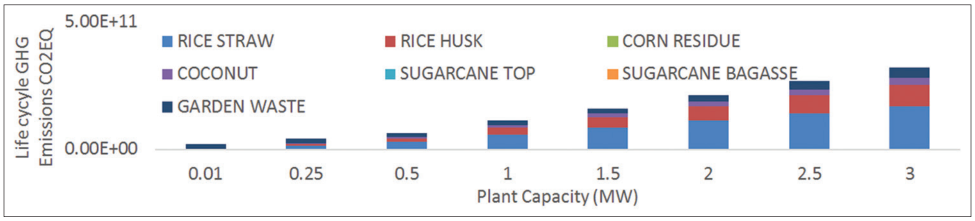
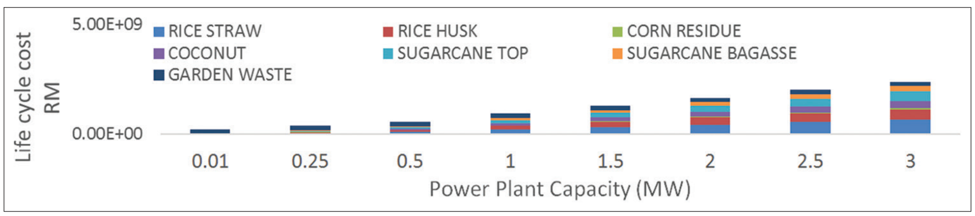


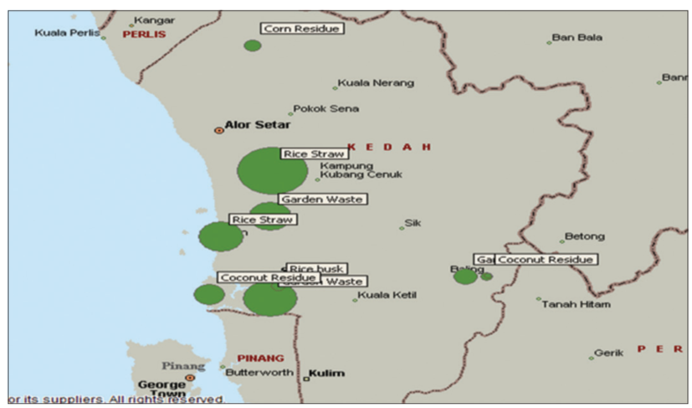
Figure 6: Life cycle cost for each crop process



give the lowest cost and GHG emission for the whole life cycle starting from production to power generation. The result for the optimisation output depends on the catchment area and electricity output. Even though the method is identical with the study in China (Shi et al., 2008), the size of supporting area of biomass supply is entirely different. In this study, the supporting area goes from 242 km^2 to 1529 km^2; however, the study in China observed the supporting area from a minimum of 10,800 km^2 to a maximum of 15,800 km^2 (Shi et al., 2008). The distinction is due to the different size of case study; the present research has a case study with a total size of 9427 km^2; whereas the China case study area was 153 400 km^2 (Shi et al., 2008). The calculated value of supporting area per total area in this study is given as 9.05%, while the China case study's result was 8.9%. The table below displays the area size for optimised GHG emission and cost. However, a study in locating the optimum bioenergy facility was conducted based on the objective function of investment yield (Athanasios and Tatsiopoulos, 2010). Figure 7 shows the optimum location and biomass resources for electricity generation in Kedah. The optimised electricity generation obtained 1.61 MW for the total power generation. The optimum design of power plant used garden waste as fuel, followed by rice straw.

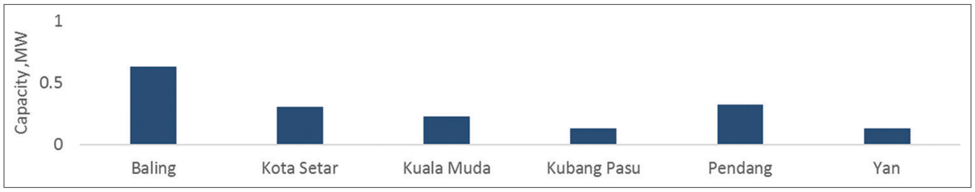
According to (Idris et al., 2018), employing biomass blending could be achieved by implementing a carbon emission scheme in the respective country or nation. As a result, any GHG emission released into the atmosphere should be paid by the energy industry. Figure 8 shows the optimum power plant locations in

Figure 7: The optimum location and biomass resources for electricity generation in Kedah



Kedah. Baling has the potential to generate the optimum capacity with 0.6 MW of electricity output by using garden waste as the main fuel. It means that the maximum power of electricity could be generated at each zone from 0.05 MW up to 0.6 MW. These six zones were shortlisted for biomass-based electricity generation due to minimum emission and cost per output electricity generation. Rice straw had become less prevalent due to the high cost for rice straw collection and transportation. The bulky bale size increased the number of lorries needed to transport the resource to the power plants; hence it increased both emission as well as cost. It is suggested that the biomass-based power plants in Kedah could only generate electricity up to 1.6 MW.

Figure 8: Optimum power plant location



4. CONCLUSION

The most potential biomass resources that are available in the northern region of Malaysia are chosen, namely rice straw, rice husk, garden waste, corn residue, sugarcane bagasse, and coconut residue. The life cycle GHG emissions are varied from 0.02 kg/kWh to 6400 kg/kWh and life cycle cost varied from RM 0.09/kWh up to RM 25.37/kWh. The optimised electricity generation obtained 1.61 MW for the total power generation. The optimum design of power plant used garden waste as fuel, followed by rice straw. Baling has the potential to generate the optimum capacity with 0.6 MW of electricity output by using garden waste as the main fuel. It means that the maximum power of electricity could be generated at each zone from 0.05 MW up to 0.6 MW. Hopefully, this result provide the guideline for decision maker to implement the renewable energy in the future.

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