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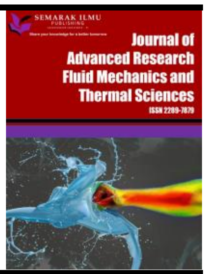

Optimum Design on Integration Biogas into Fuel Cell System in Malaysia: Economic and Environmental Aspect

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ABSTRACT

Transition to renewable energy in electricity generation need a serious study in variety of issues. Environment and economic perspective become the vital issue that need to study in local condition for penetration new concept of energy resources. Feeding a biogas into the fuel cell system seems an attractive way to less dependent on fossil fuel-based electricity generation. This study aims to optimize the plant location based on two aspect environment and economic. Capacitated Plant Location Model (CAPLOC MODEL) were used in determine the optimized location of the plant. The optimum design of power plant in Sarawak solely generated 847.91 MW and Pahang about 604.26 MW. Hopefully, the outcome of the study can provide the information for stakeholder in choosing the location for future energy system in Malaysia.

1. Introduction

Biogas productions play a significant performance in improving energy system and enhancing energy security globally. Related to this there have a positive trend in number of biogas plant operated in the world with 46% increase [1]. By the year 2022, biogas industry will contribute about RM 8.3 billion (USD 2.3 billion) in Malaysia, and up to RM120.1 billion (USD 33 billion) for world global contribution [2]. Related to this, Malaysian government also support the small-scale biogas generation units could be set up to convert waste into biogas for energy production [3]. Practically, this biogas is consumed for rotating the turbine in producing electricity. Nonetheless, utilization of biogas in small scale turbine power generators may lead to the worst techno-economic conditions [4]. Feeding biogas into fuel cell system become an option to varieties the application of these gases. The feasibility on biogas as input into the SOFC system has been trusted and the largest power plant in Europe with capacity of 174 kW already installed in 2017 [5]. However, high capital cost of biogas

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fuelled Solid Oxide Fuel Cells (SOFC) remains a crucial obstacle to positioning in industry [6]. The integration of biomass gasification with SOFCs offers the potential of highly efficient and renewable power generation, primarily in modular solutions [7]. According to [8], previous studies on optimum model of plant location can be categorized into two parameters:

i. identification of appropriate locations (siting) for bioenergy facilities through land suitability analysis
ii. determination of plant capacities through allocation of feedstock sources in addition to siting.

Similar to this [9], the study established a model to resolve the multi-criteria decision problem of finding the most appropriate location for biogas plant, that consider several factors such as the supply production, population density, distance to power plants and type of transport. However previous studies only focus for their own localities. Hence, this paper aims to

i. identify the suitable state in Malaysia for located biogas feeding fuel cell system
ii. optimum plant location in state of Malaysia considering the environment and economic aspect.

2. Methodology

This study considers the environment and economic parameter for model the optimum power plant. Figure 1 indicate the overall research flow. For both parameters are done in previous studies. The data from previous study are applied in this article.

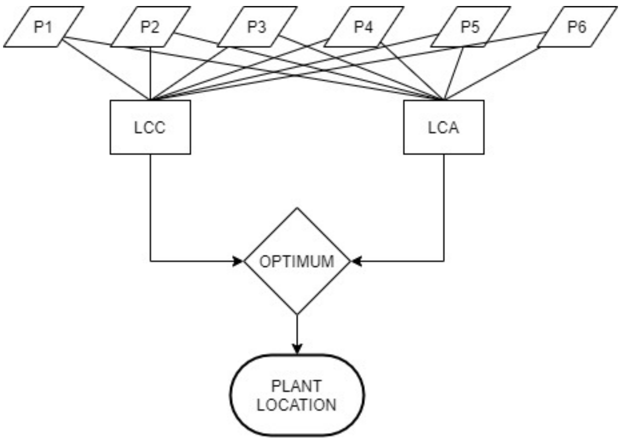


Fig. 1. Overall research flow in this study

Table 1 list the detail data use in this article.

Table 1
Data applied in this article

Parameter	Resources	Ref.
Environment	Biogas Fed-fuel Cell Based Electricity Generation: A Life Cycle Assessment Approach	[10]
Economic	Life cycle cost of biogas feeding into fuel cell: Case of Malaysia	[11]

In order to analyse the optimum plant, result for previous obtained data were applied in this article.

Linear regression equation is used in order to plot the best suitable location of implemented the biogas feeding into fuel cell system. Table 2 is list of palm oil mills and of equation for both environment and economic parameter. The equation is tabulate from each reallocation of available biogas resources in each state. The assumption was made where all palm oil mill register under MPOB will generate the biogas from POME. In this study, considering all the palm oil mills registered under Malaysian Palm Oil Board [12]. Table 2 list the number of mills that consider in this study.

Table 2
List of palm oil mill and equation for environment and economic parameter

State	Number of mills	Environment	Economic
Johor	63	$\hat{y}$ = 0.00002X + 0.39295	$\hat{y}$ = 0.00006X + 2.38669
Kedah	6	$\hat{y}$ = -0.00002X + 2.80672	$\hat{y}$ = -0.00001X + 0.57095
Kelantan	11	$\hat{y}$ = -0.00008X + 23.06709	$\hat{y}$ = -0.00005X + 0.69962
Negeri Sembilan	16	$\hat{y}$ = 0.0785x + 0.0678	$\hat{y}$ = 0.1804x + 9.7814
Pahang	72	$\hat{y}$ = 0.0045x + 0.6396	$\hat{y}$ = 0.0152x + 10.594
Perak	47	$\hat{y}$ = 0.00005X + 0.44383	$\hat{y}$ = 0.00004X + 10.49878
Sabah	131	$\hat{y}$ = -0.00005X + 0.98613	$\hat{y}$ = -0.00009X + 11.40371
Sarawak	84	$\hat{y}$ = 0.00001X + 0.97785	$\hat{y}$ = 0.00002X + 11.08648
Terengganu	13	$\hat{y}$ = -0.0008x + 0.3645	$\hat{y}$ = -0.0323x + 10.461

Both environment and economic parameters are applied the similar process as mentioned in Figure 1, starting from plantation, transportation of fresh fruit bunch (FFB), biogas production, transportation of biogas, biogas storage and fuel cell system. The data obtain from [10,11] are tabulate to get the linear regression equation. Eq. (1) applied to calculate the most potential of location the biogas feeding fuel cell system. Where L_D is the location district, E_G is the environment value, E_C is the cost and n number of districts for each state in Malaysia.

$$L_D = Min \sum_1^n E_G \times E_C \qquad (1)$$

Modelling Language and Optimizer (LINGO 17.0) were used to run the analysis, using CAPLOC MODEL (Capacitated Plant Location Model). Two primitive set are declared in this model the PLANT (Number of mills, P) and SYSTEM (Potential of Power Plant in each state). There are two sets of constraint in this model:

i. each plant cannot supply more than its capacity
ii. each state only consists of one SYSTEM

Hence, the objective set in this model were optimized the electricity output for each state in Malaysia with minimum of life cycle cost and emissions. Eq. (2) is used for setting the objective and Eq. (3) and Eq. (4) applied for the constraint. There are two sets of decision variables in this model. The *VOL* attribute, defined on the *ARCS* set, represents as plant capacity volume from the aspect of environment (GHG) and economic (COST) along each arc. The *OPEN* attribute, defined on the *PLANTS* set, is used to represent the plants that are open. Specifically, *OPEN (p)* is 1 if plant *p* is opened, else it is 0. DEMAND is defined the plant capacity of electricity generation.

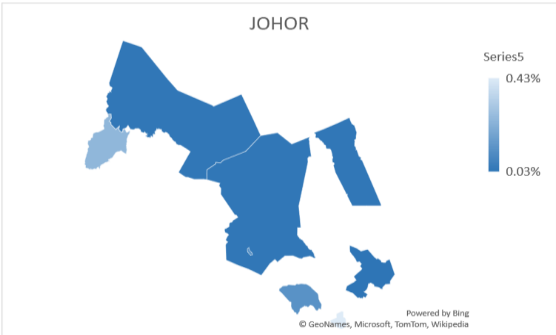
MIN = @SUM(ARCS: GHG * VOL) +@SUM(ARCS:COST*VOL)+ @SUM(PLANTS: SYSTEM * OPEN) (2)

@FOR(SYSTEM(J): [DEMAND] (3)

@SUM(PLANTS(I): VOL(I, J)) >= DEM(J) (4)

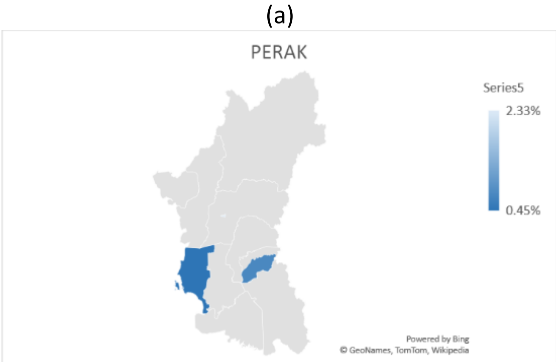
3. Results

Malaysia main biogas productions are from palm oil mill waste residue. As a tropical country all land location in Malaysia are suitable for oil palm plantation. Figure 2 show the best location district per state for minimum environmental and cost considering. The blue colour indicates the suitable district for implement this system considered the environment and cost parameters. Johor, Sabah, Sarawak, and Pahang have more districts that suitable for biogas feeding fuel cell system. In Johor, the district of Kota Tinggi gives the minimum amount of emission and cost parameters. Follow by Kluang, Mersing and Segamat.



(a)

(b)



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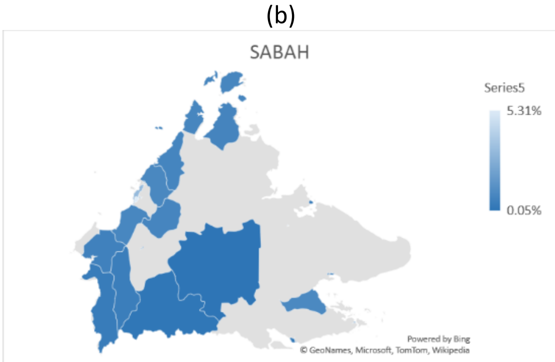

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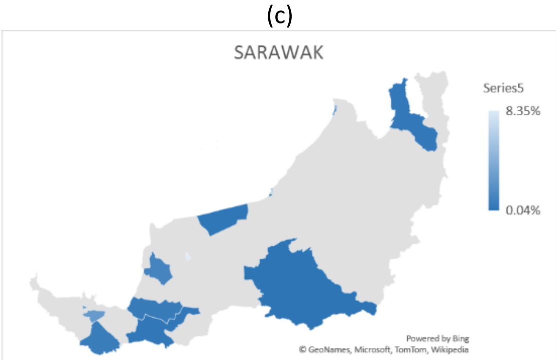

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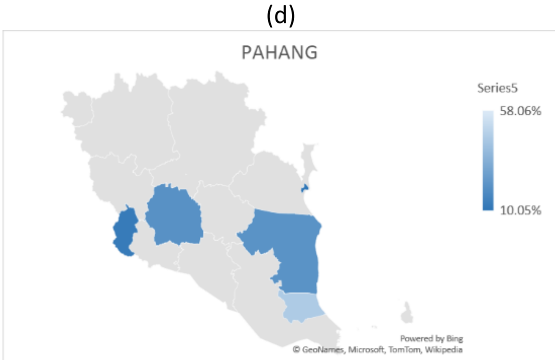

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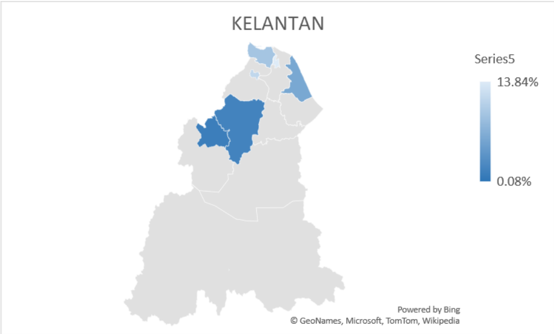

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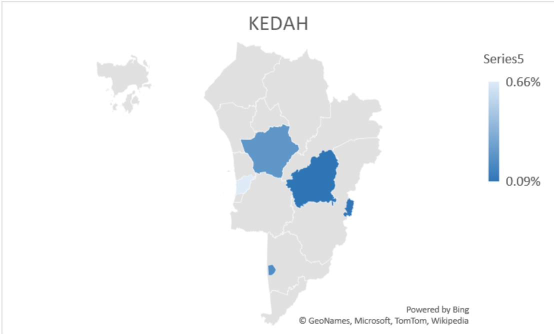

(h)

Fig. 2. (a)-(h) Mapping location for each state in Malaysia

Figure 3 show the result for optimum plant location in Malaysia considering the economic and environment aspect.

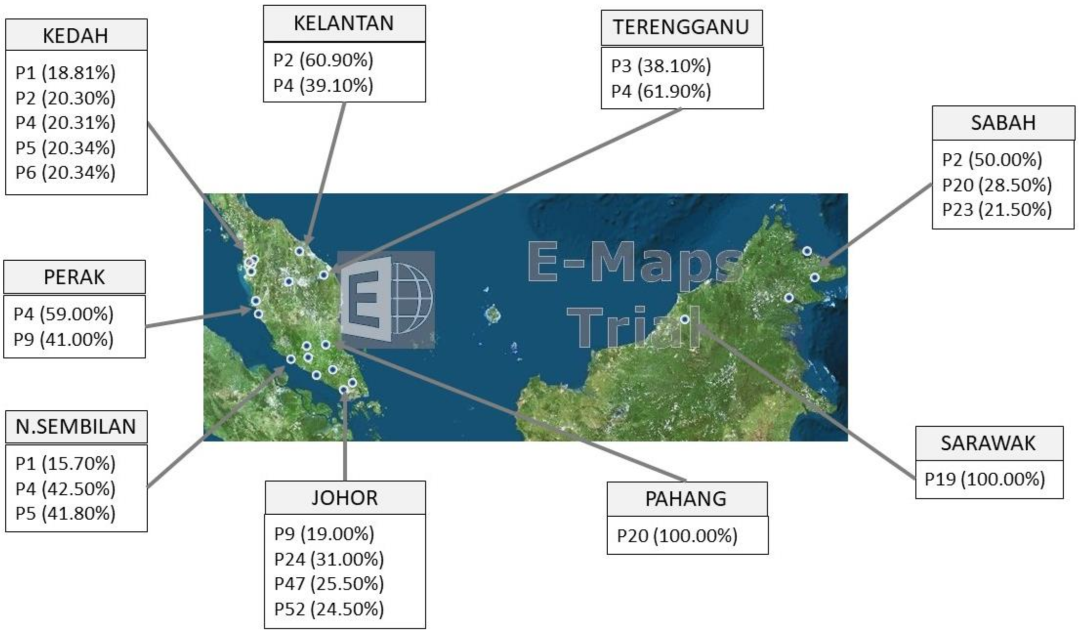

Fig. 3. Optimum plant location for each state in Malaysia

Table 3 list the details plant location with capacity for optimum model consider economic and environment. Based on table about 23 potential plant sites in Malaysia are listed for optimized performance with minimum cost and emissions. It seems Pahang and Sarawak has solely one plant in their state. Sarawak is the largest state in East Malaysia while Pahang is the largest state for Peninsular Malaysia or Western Malaysia. Increasing number of plant show that reducing plant size[8]. Currently, there are many studies refer to small and medium biogas production and power plants only[13].

Malaysia can be introduced to fuel cells as alternative renewable energy resources with the strong support from government particularly the spreading of funds for fuel cell expansion in Malaysia[14,15]. The fund is needed particularly for significant investments in infrastructure [16,17].

Table 3
List the details plant location with capacity for optimum model consider economic and environment

State	Name	Location	LABEL	Capacity, MW
Kedah	Setia Kawan Kilang Kelapa Sawit	Kulim	P1	8.99
	Solid Orient Holdings	Baling	P2	9.71
	Arah Kawasan Sdn Bhd	Bandar Baharu	P4	9.72
	KKS Taclico Company	Kulim	P5	9.73
	Kilang Kelapa Sawit Batu Lintang	Bandar Baharu	P6	9.73
Perak	Kilang Kelapa Sawit Changkat Chermin	Manjung	P4	218.89
	Kilang Kelapa Sawit Flemington	Hilir Perak	P9	152.11
N. Sembilan	Kilang Sawit Serting	Jempol	P1	21.94
	Kilang Kelapa Sawit Sua Betong	Port Dickson	P4	59.39
	KKS Nam Bee	Tampin	P5	58.42
Johor	KKS Kahang	Kluang	P9	119.46
	KKS Lok Heng	Kota Tinggi	P24	194.92
	Kilang Sawit Muar Bhd	Muar	P47	160.33
	Kilang Kelapa Sawit United Bell	Pontian	P52	154.04
Pahang	KKS Lepar Utara 4	Bera	P20	604.26
Kelantan	Kilang Kelapa Sawit Kemahang	Tanah Merah	P2	40.51
	Kilang Sawit Liziz	Gua Musang	P4	26.00
Terengganu	KKS Bukit Kapah	Hulu Terengganu	P3	42.41
	KKS Sungai Tong	Setui	P4	68.89
Sabah	Dumpas Palm Oil	Tawau	P2	503.97
	KKS Sungai Ruku	Kinabatangan	P20	287.26
	KKS Bukit Mas	Kinabatangan	P23	216.71
Sarawak	Asian Plantation Milling Sdn Bhd	Miri	P19	847.91

4. Conclusions

Malaysia as tropical country has abundant of oil palm production. Most applicable district for obtained the minimum of environment and cost perspective is from state of Johor, Sabah, Sarawak, and Pahang. The optimum design of power plant in Sarawak solely generated 847.91 MW and Pahang about 604.26 MW. Other's state can have two to three power plant based on the percentage generation. This outcome can provide the information to the stakeholder for them to choose the suitable location for biogas fuel cell system electricity generation

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