CHEMICAL ENGINEERING TRANSACTIONS

VOL. 78, 2020

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-76-1; **ISSN** 2283-9216

DOI: 10.3303/CET2078055

The Potential of Biomass Fuel and Land Suitability for Biomass Power Plant based on GIS Spatial Analysis in the Nakhon Ratchasima Province, Thailand

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The government's new electric power development plan (PDP2018) focuses on developing renewable energy to the fullest potential in each area. One of the most valuable renewable energy sources in Thailand is biomass from the agricultural sector. Thailand has a target of 3,496 MW of electricity generated from biomass fuel, with the focus on the development of community biomass power plants. The main objectives of this research are to analyse the potential of energy generation from the harvesting of biomass residuals and to analyse the optimal locations for constructing a biomass power plant using multiple criteria analysis, Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Geographical Information System (GIS) in Nakhon Ratchasima province, Thailand. The results indicate that the study site had a total area of 12,876.01 km^2 of rice, cassava, sugarcane and maize planting areas in 2015, which resulted in a total crop production of 21.195 Mt, with an estimated total biomass residual of 9.098 Mt/y. Some portions of this biomass are used for existing electrical generation and other usages, totaling 4.889 Mt or equivalent to 53.7 % of the total estimated biomass residual. The remaining biomass residual is 4.209 Mt or 46.3 %, which can be used to generate electricity of 386.2 MW per year Land suitability evaluation is based on relevant physical and environmental indicators with specific criteria, as well as the government policy, law regulations, existing land use and the remain potential of crop residuals used as a fuel. It can be concluded that 5,284.85 km^2 or 26.8 % of a total area are assessed as being best suitable for constructing the biomass power plant. Land suitability is mostly located in the western and southeastern regions of the province. The results of the evaluation of multiple crop biomass power generation potential with pixel-based data structure provide a map of biomass fuel source distribution and power generation potential. The potential shows the amount of electricity that is expected to be produced per unit area which is more accurate in terms of spatial than statistic approach. In addition, the spatial accuracy of electricity production potential data is also an important factor in determining which areas are suitable for a power plant, especially for small power producers (SPPs) such as villages or sub-district level communities.

1. Introduction

The biomass power plant is a power plant that uses residual materials from agricultural sectors as a fuel for electrical generation (Wongwadhunyoo, 2007). Biomass fuels lead to energy security because biomass is an energy source that can be replenished or increased in a short time. In contrast, fossil energy sources take a long time to develop and will come to an end. Biomass energy is a clean fuel which helps to mitigate contributions to global warming (DEDE, 2008). Thailand has a campaign to save energy and promote the usages of renewable energy from nature, especially from biomass energy, which has the second-highest potential after solar energy. The government has a policy to promote the establishment of a community power plant in the form of cooperatives, that will help the community earn income from owning the power plant and lead to co- environmental benefits. One of the critical questions about this power producer is how much remaining harvesting biomass residual will be left after being used for other purposes? What is the electricity production potential? And where should the new power plant be located?

Paper Received: 18/04/2019; Revised: 01/09/2019; Accepted: 02/10/2019
Please cite this article as: Wannasiri W., 2020, The Potential of Biomass Fuel and Land Suitability for Biomass Power Plant based on GIS Spatial Analysis in the Nakhon Ratchasima Province, Thailand, Chemical Engineering Transactions, 78, 325-330 DOI:10.3303/CET2078055

In Thailand, the evaluation of energy potential from biomass residual is mostly reported in the terms of the statistics on the province level. These data cannot provide information about where biomass residuals are located and distributed. To solve this problem, the Geographical Information System (GIS) is the best solution for analysing the spatial distribution of both the availability and the utilisation of biomass. A few studies focus on the potential of biomass residuals in the form of polygon feature (Nurariffudin M., et al, 2018) or according to the provincial boundary, which cannot show the energy potential per unit area or of smaller areas. This analysis level is not sufficient to be useful for determining the location of the community power plant or Small Power Producer (SPP). Moreover, several studies focus on evaluating the potential of individual energy crops, which cannot reflect the total potential of an area with multiple energy crops. Almost all of the research in Thailand has an emphasis on the study of a suitable area for the construction of biomass power plants by considering a few of the relevant factors (Khidhathong et al., 2014). With regards to the evaluation of land potential, it is challenging to consider relevant factors such as the physical, environmental, economic, social and legal aspects which must be accurate and up-to-date (Rosso et al., 2017). There are several methods for multi-criteria analysis including Fuzzy Analytic Hierarchy Process (Fuzzy AHP). Fuzzy AHP is appropriate to extract the potential areas by using multiple factors and is consistent with raster-based data structure. All factors and criteria will be adjusted to the same standard before applying the spatial analysis methods using the GIS technique (Jeong and Gómez, 2018).

The main objectives of this research are to analyse the potential of energy generation from several types of biomass including rice, sugarcane, cassava, and maize; and to analyse the suitable area for constructing the biomass power plant in Nakhon Ratchasima province. The spatial distribution of biomass fuel and electrical potential (MW) will be identified in terms of unit area (raster-based). This information is the basis for the evaluation of the availability of biomass for energy production and the economic appraisal of the new power plants. The results of the study will be beneficial when determining the policies to promote energy crops and in establishing the additional biomass power plants.

2. Study area

Nakhon Ratchasima province is situated in the Northeastern region of Thailand. The topography is a plateau 150-300 meters above mean sea level with the total areas of 20,493.96 km^2. About 72.1 % of the total area is used for agricultural production. About 87.8 % of the agricultural area is used for the energy crops including rice, sugarcane, cassava, and maize resulting in massive amounts of crop residuals (NSTDA, 2015). Figure 1 illustrates the land use type in the study area.

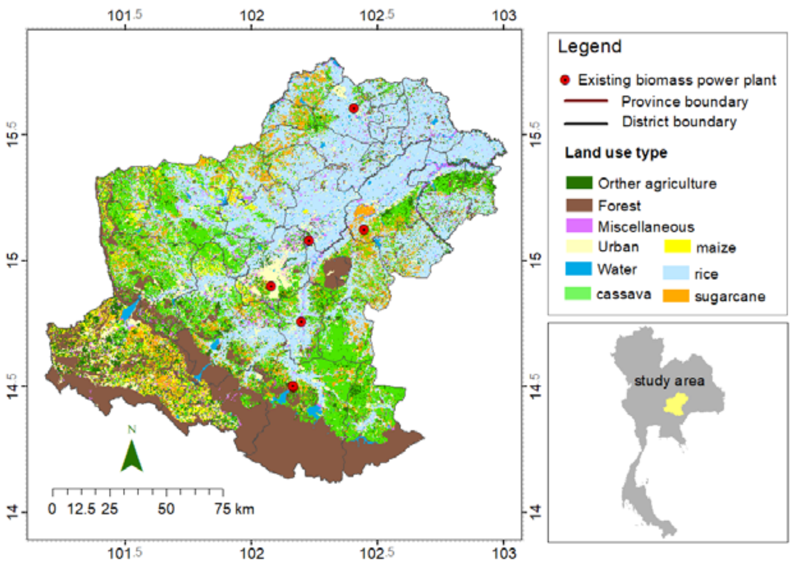

Figure 1: Land use type in Nakhon Ratchasima province

3. Methodology

3.1 Evaluation of the potential of biomass residuals for power plant

Polygon features of energy crop cultivation area operated by the Land Development Department (LDD) were converted to the raster data format with 30 m x 30 m cell size. Crop productions were estimated by multiplying the total planting areas with the productivity index per area at the sub-district level. The productivity index refers to the report of the Agricultural Economics Office in 2015. Biomass volumes were evaluated by multiplying the total crop productions with the ratio of crop residuals per total weight. Then the results were subtracted from several of biomass residuals that are utilise for other purposes such as fuels, fertilizer and animal feed. The potential of thermal energy (PE_{Th}) obtained from fuels mass is calculated by Eq(1),

$$PE_{Th} = M_R \times hv \times 1{,}000 \quad (1)$$

where PE_{Th} is a potential of thermal energy (MJ), M_R is remaining biomass residuals (t), and hv is heating values of biomass fuel (MJ/kg)

Crop residual ratio, biomass utilisation ratio and specific heating values which refer to the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy were summarised in Table 1.

Table 1: Crop residual ratio, utilisation ratio and specific heating values of each biomass type

Crop type	Biomass type	Residual ratio	Utilization ratio	Heating value (MJ/kg)
1. Paddy rice	1.1 Straw	0.49	0.50	12.33
	1.2 Husk	0.21	0.70	13.52
2. Sugarcane	2.1 Leaves and cane tops	0.17	0.10	15.48
	2.2 Bagasse	0.28	1.00	7.37
3. Cassava	3.1 Stalk and leaves	0.09	0.05	18.42
	3.2 Rhizome	0.20	0.60	5.49
4. Maize	4.1 Stalk and leaves	1.84	0.05	9.83
	4.2 Silk	0.24	0.90	9.62

The Potential of Electrical energy (PE_{Elec}) is calculated by using Eq(2),

$$PE_{Elec} = \frac{PE_{Th}\ x\ Eff\ (\%)}{hr\ x\ 3.6\ x\ 1{,}000)} \quad (2)$$

where E_{Elec} is the potential of electrical energy (MW), E_{ff} is power plant efficiency which assumed as 20 %, hr is operating hours of power plants which has an average of 7,920 h/y.

The analysis procedure is illustrated in Figure 2.

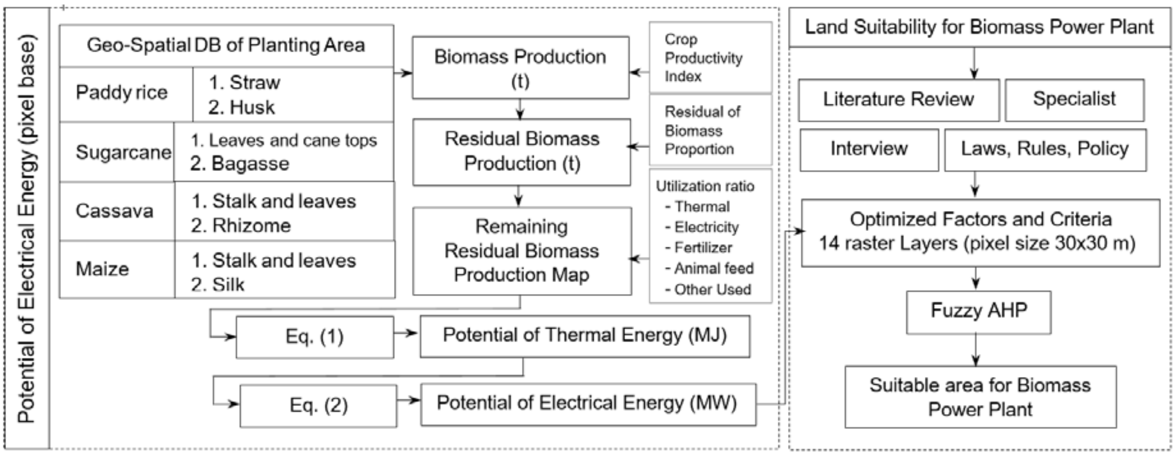

Figure 2: Research methodology framework

3.2 Analysis of the land suitability for constructing the biomass power plant

Land suitability for biomass power plant construction was analysed by considering the relevant factors and specific criteria which are related to the physical, existing land use, environmental indicators, cost, public utilities, the government policy, and law regulations in the total of 14 factors. From the literature review, interviews with people whose work relates to energy crops, and by determining weighted score of factors and criteria by the specialists. All factors in the format of grid data were listed and weighting scores were optimised using multiple criteria analysis based on Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and GIS. All factors and criteria will be adjusted to the same standard. The row average technique method, which is a hierarchical analysis technique, was applied for assigning the weight score and priority of each element. The zonal statistic based on focal analyses is used to categorize the level of suitable zone for biomass power plant location.

4. Results and discussion

4.1 Potential of energy generation from rice

The total area of rice cultivation is 6,652.89 km^2 including both major and secondary rice production providing a total yield of 1.478 Mt of rice. Rice harvesting biomass residuals from those total yields are approximately 1.035 Mt/y. The remaining rice residuals after deducting from usages in other purposes is approximately 0.455 Mt. Under the assumption that there is no burning on the field, 0.455 Mt of straw and husk can be used to generate electricity approximately equal to 40.2 MW. However, in practice, there is a large number of rice straws that have been burned by local farmers in the rice fields.

4.2 Potential of energy generation from sugarcane

Nakhon Ratchasima province has a total area of 1,548.13 km^2 of sugarcane cultivation. There is a total sugarcane yield of approximately 10.343 Mt/y which results in the biomass residuals of 4.655 Mt derived from leaves, cane top and bagasse. The local farmers usually prefer to burn leaves and cane top to be a carding before harvesting. Under the assumption that there is no burning on the field, 1.583 Mt of remaining leaves and cane top can be used to produce electricity approximately equal to 171.8 MW. Bagasse which is the by-product from crushing is used as a fuel. Thus, the potential for energy generation from bagasse is zero.

4.3 Potential of energy generation from cassava

The total area of cassava cultivation is 3,939.79 km^2 provides an overall yield of 8.987 Mt of cassava. Stalk, leaves, and rhizome is the part of cassava residuals with a total number of 2.606 Mt with remaining of 1.487 Mt. It can produce electricity of 99.3 MW and 27.7 MW from the total cassava stalk, leaves, and rhizome. Stalk and leaves are not yet being utilised for energy generation. Some of the cassava stalks have been used for the cultivation in the next season and leaves are usually burned on the farm. In additions, rhizome is the residual materials from the production of tapioca starch and is stored at the flour production plant.

4.4 Potential of energy generation from maize

The total area of maize cultivation is 735.19 km^2. The estimated number of biomass residuals is 0.803 Mt which deriving from stalk, leaves, and silk. Stalks and leaves are often burned after harvesting, and about 0.119 Mt/y were used for raising animals and making fertiliser. Under the assumption that there is no burning on the field, 0.684 Mt of maize stalks and leaves can be used to generate electricity approximately equal to 47.2 MW. Silk, the waste from animal feed production process, is used as a raw material for ethanol production, which results in the small portion for electrical generation.

Table 2: The biomass and energy potential from the biomass of four types of crops in Nakhon Ratchasima

Crop type	Residual type	Biomass residuals (Mt/y)	Biomass used (Mt/y)	Remaining biomass (Mt/y)	Potential of energy (MW)	Percent (%)
1. Paddy rice	1.1 Straw	0.724	0.362	0.362	31.3	8.1
	1.2 Husk	0.310	0.217	0.093	8.8	2.3
	Total	1.035	0.580	0.455	40.2	10.4
2. Sugarcane	3.1 Leaves and cane tops	1.758	0.176	1.583	171.8	44.5
	3.2 Bagasse	2.896	2.896	0.000	0	0
	Total	4.655	3.072	1.583	171.8	44.5
3. Cassava	2.1 Stalk and leaves	0.809	0.040	0.768	99.3	25.7
	2.2 Rhizome	1.798	1.079	0.719	27.7	7.2
	Total	2.606	1.119	1.487	127	32.9
4. Maize	4.1 Stalk and leaves	0.710	0.036	0.675	46.5	12
	4.2 Silk	0.093	0.083	0.009	0.6	0.2
	Total	0.803	0.119	0.684	47.2	12.2
Grand Total		9.099	4.889	4.209	386.1	100.0

In the study area, there is a total planting area of 12,876.01 km^2 of rice, cassava, sugarcane and maize in 2015. It can be estimated that the total biomass residuals of 9.099 Mt/y. Some of which are used for electrical generation and other usages, totally 4.889 t or equivalent to 53.7 % of the total estimated biomass. The remaining biomass that has not yet been utilised is 4.209 Mt or 46.3 %, which can be used to generate electrical 386.1 MW per year. Referring to figure 3, the region that has the potential to produce energy from biomass ranging from 4.41 MW to 8.75 MW per year is mostly in the Pak Chong, Dan Khun Thot, and Si-Khio district.

However, in the practical context of Thai local farmers, there is difficulty in using some biomass residuals as a fuel in the power plant because of burning culture, harvesting method and transportation costs. Therefore, the government and related organisations have to promote the burn reduction campaign as well as determine the appropriate purchase price and transportation costs.

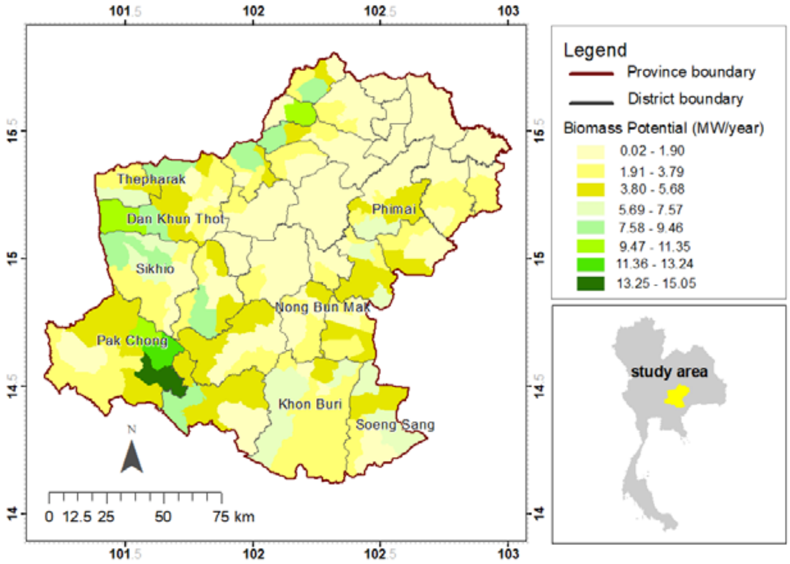

Figure 3: Potential of energy generation from biomass residuals in Nakhon Ratchasima

4.5 The land suitability for constructing the biomass power plant

The results of this land suitability evaluation reveal that Nakhon Ratchasima province has a total area with high suitability of 5,284.85 km^2 or 26.87 % of the total areas. The land suitability can be divided into three levels including high, moderate, and low level with a total area of 514.68 km^2, 1,977.32 km^2 and 2,764.06 km^2 or equivalent to 2.62 %, 10.20 %, 14.05 %.

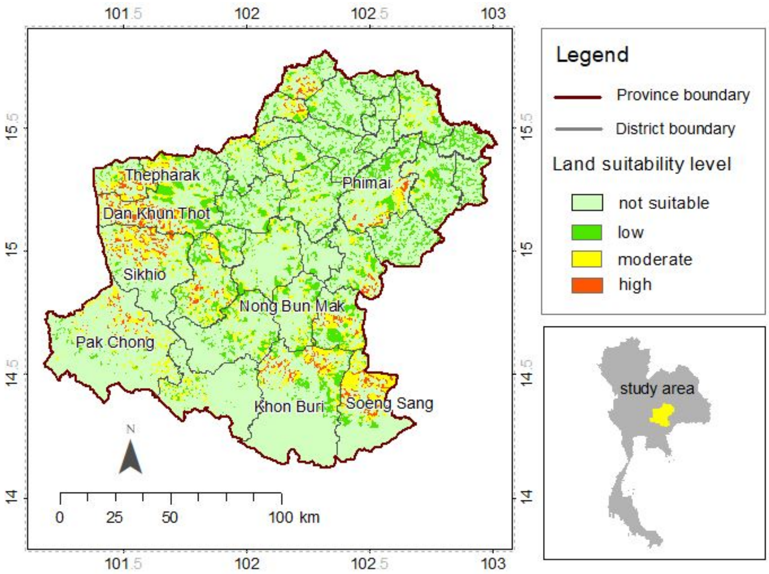

Figure 4: Land potential for setting up a biomass power plant in Nakhon Ratchasima

Figure 4 illustrates that the high suitability areas are mostly located in the western portion of the province in Dan Khun Thot, Sikhio, and Thepharak district and the southeastern region in Soeng Sang, and Khon Buri. Such regions have high suitability for generating electricity with a large number of biomass residuals as well as short distances from the road network and power line network, which are essential factors in constructing the biomass power plant. Despite the existing biomass power plants in Phimai district, there is still enough biomass potential for a new power plant. Non-suitable areas are widely distributed, especially in the southern part of the study site. However, there are important factors that must be addressed in each specific area when applying to another site including (i) availability and accessibility to crop residuals (ii) costs of residual management and transportation (iii) government policy and relevant law regulations.

5. Conclusion

The evaluations of the spatial distribution of potential areas in Nakhon Ratchasima province both for the electrical energy produced from biomass residuals and land suitability for constructing the biomass power plant using multiple criteria analysis, Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Geographical Information System (GIS) model has been completed. Nakhon Ratchasima province has a high remaining potential for energy generation from the various types of biomass including rice, cassava, sugarcane, and maize. It can approximately be estimated that the total number of biomass residuals is 9.099 Mt/y. Some of which are used for electrical generation in the existing power plant and other usages such as ethanol production, animal feed and, the papermaking industry. The remaining biomass residuals of 4.209 Mt/y or 46.3% can be converted into electrical energy of 386.1 MW.

In this study, remaining biomass residuals is ranked to be the most critical factor for evaluating the land suitability for the biomass power plant construction. The distance away from the residual sources is considered to be the second most crucial factor for the location of the power plant. The Fuzzy AHP method is appropriate for analysis when the process are several factors with different measurement units. Most importantly, the Fuzzy AHP is supporting the analysis at the pixel level and high accuracy tasks.

The results of this study indicate that an assessment of the potential of electrical energy produced from biomass representing with the raster data is a practical solution to calculate the total electrical production from various types of biomass residuals. Using the overlay functions based on spatial data analysis, it allows us to map the spatial distributions of the electrical energy potential from each plant's components. Each pixel provides information on the total biomass residuals, the potential energy that can be used to produce electricity, coordination of pixel centroid, and what type of biomass was derived. The research results will be a benefit for the power produce, farmer, and the government and related organisations both in the policy determination in energy crop plantations and the establishment of biomass power plants.

Acknowledgements

The authors gratefully acknowledge the Faculty of Liberal Arts, Thammasat University, which supports research funds.

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