IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: Shahid Ali and Jompob Waewsak 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **265** 012021

IOP Conf. Series: Earth and Environmental Science **265** (2019) 012021 doi:10.1088/1755-1315/265/1/012021

GIS-MCDM approach to scrutinize the suitable sites for a biomass power plant in southernmost provinces of Thailand

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Abstract. Identifying suitable locations for biomass base facility is a tremendous task. This study developed a GIS-AHP based methodology to determine the suitable locations for 9.5 MW biomass facility considering para rubberwood as a biomass resource in southernmost provinces of Thailand. In total 10 siting criteria under environment and socio-economic capacity was assessed. The area needed to secure a feedstock for a 9.5 MW facility for sustainable operation, using an assumption-based method was also conducted. This study found that out of 13,941 km2 of the study area, 4,890 km2 (35%) is either highly or moderately suitable to establish para rubberwood-based energy facilities. Where 21 power plant can be constructed in the study area considering both high and moderately suitable areas and that capacitates to generate 1580 GWh/year.

1. Introduction

Energy is a key player in the industrial and economic growth of all the countries [1]. 82% of the world's energy need is based on fossil fuels which is one of the main causes behind global warming. The emissions in forms of CO_2 were 33.9 billion t/yr and that expects to reach 42.8 billion t/y by 2050 [2]. This rising global warming concern has constrained the expansion of energy projects around the globe and has pushed the countries to develop strategies to avoid or mitigate CO_2 emission as much as possible [3]. One of the approaches is to promote renewable energy options which are environment-friendly with least or no significant impact on the surrounding ecology. The commonly used renewable energy sources are solar, wind, hydro, biomass and geothermal etc. [4].

Thailand being one of the rapidly developing countries holds a huge capacity for renewable energy resources [1, 5]. The leading renewable resources in Thailand are solar and biomass energy [6, 7]. Biomass-based power generation, which has a low carbon footprint, is deemed as the best energy option in countries such as Thailand, where the resources are in abundance [8]. The exploration to biomass-based energy was started in 1992 for the first time in Thailand [9, 10] and it expects to generate 3,940 MW of electricity using biomass by 2021 which will be scaled up to 5,570 MW until 2036 [6]. Agricultural residues, animal wastes and other organic wastes are some of the commonly used biomass resources around the world [11].

In Thailand, one of the commonly available biomass resources is para rubberwood that weighs 180 t/ha of biomass which is being stored directly from sunlight [10]. In Thailand, the southern part is known as one of the largest rubber producing regions in the world since 1990 [12], where out of the 2.72 million hectares (ha) of the peninsular area, para rubber plantation covers 1.67 million ha [10].

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However, one of the biggest challenges associated to biomass resources is they are not densely populated in one location, and this makes it critical to secure a long-term feedstock which is essential for the sustainability of biomass-based energy [13]. In such conditions it becomes vital to develop an approach to overcome the dilemma of site selection that could also be coupled with various other environmental and economic challenges such as accessibility land use, electricity grid availability etc. [14].

Recently, Geographical Information System (GIS) has emerged as one of the most promising tools to deal with spatial data analysis such as renewable energy resources assessment and it can also manipulate and store apparently distinct data sets smoothly [15, 16]. It has frequently appeared in biomass-based energy development studies using forest and agricultural residues as a resource [13, 15, 16]. In addition to this, the Multi-criteria decision making an analysis (MCDMA) has revolutionized the entire decision making spectrum that can be integrated with GIS to produce maps of our choice in resource assessments projects [13]. GIS-MCDMA approaches have frequently appeared in many similar studies [17–19]. However rarely any study could be found that has utilized GIS-MCDM for para rubberwood biomass exploitation for energy purpose.

Therefore the aim of this research work is to assess the suitable para rubberwood biomass spots in southernmost provinces of Thailand by utilizing environmental and socio-economic factors. This study also aims to identify the area need to secure a feedstock to operate a 9.5 MW biomass facility for a time period of 20 years for which biomass of 350 t/day is required. The theoretical power output in GWh/year is also calculated at the end.

2. Materials and method

In order to find the most suitable sites for biomass-based power facility considering para rubberwood, the first step is to identify the important siting criteria that may comply with the national and international guidelines as well as the ground conditions of the study area. Therefore, the method section has been identified as under in the following sequences.

2.1. Siting criteria for para rubber wood biomass

To be having a nearby feedstock cannot be justified as the sole reason to set up a biomass facility, therefore in this study we have considered a brief set of environmental and socio-economic parameters.

2.1.1. Environmental siting criteria. Environmental preservation is one of the main aims of renewable energy development, therefore in the light of previous literature, the following environmental criteria were considered [13, 20, 21].

a. Waterbodies: A buffer of 500 meters was established surrounding lakes and rivers.
b. Watershed: Class 1 and 2 watersheds were excluded.
c. Floodplains: Areas less than 300 meters to floodplains were excluded.
d. Important places: 500 meters buffer was established surrounding parks and temples.
e. Land use: Residential areas, important places, military camps, reserved forest were excluded.

2.1.2. Socio-Economic siting criteria. Socio-economic factors are directly linked to the social lives and the economic gains of the development projects. In this study, they were carefully considered in compliance with the previous literature [11, 13, 21, 22].

a. Residential buffer: 1000 meters buffer was established in surrounding to residential areas.
b. Slope: Areas having slope above 15% were excluded.
c. Elevation: Areas having elevation above 200 meters were excluded.
d. Main roads: Proximity to roads was restricted to 10 km.
e. Transmission lines: Proximity to transmission lines were restricted to 10 km.

2.2. Study area and data description

This study area encompasses an area of 13,941 km² that include three southernmost provinces of Thailand, name as Pattani, Yala and Narathiwat, along with and four districts (Chana, Na Thawi, Thepha and Saba Yoi) of Songkhla province (see figure 1). This region has a tropical monsoon climate and receives a lot of rain every year [1] and it is hot during summer which is considered a highly suitable climate for rubber plantation [12]. Rubber is considered as one of the main sources of income for the local farmer, therefore, it has been planted previously in these areas and some of them are as young as 4 years, whereas most of them are as old as 20 year and above. This can also be used for energy purposes if the feasibility is properly investigated, as at recent southern region shown as a growing trend in terms of energy demand due to hot weather and growing use of air conditioners [23].

The data need for this study were collected from both literature and government organizations. Experts opinion were also employed for decision-making purposes. The chosen experts were limited to university professors and engineer with a minimum of 3 years' experience related to biomass energy development. However, a brief detail on datasets used may be found in table 1.

Table 1. Data sources in this study.

Sr. No.	Data type	Data format	Data source	Edit source
a)	Floodplain	Vector	GISTDA	Research Center in Energy and Environment (RCEE), Thaksin University (Phatthalung campus).
b)	Land cover	Vector	DLD	
c)	Slope/elevation	Raster	ALOS	
e)	Residential Area	Vector	DLD	
f)	Road network	Vector	DLD	
g)	Distribution System	Vector	PEA	
h)	Watershed/waterbody	Vector	DLD	

Note: Department of Land Development (DLD) Thailand; Geo-Informatics and Space Technology Development Agency (GISTDA), the space agency and space research organization of Thailand; Japan's Advanced Land Observing Satellite (ALOS), also called Daichi; Provincial Electricity Authority (PEA) of Thailand

2.3. GIS-AHP Application

As the aim of this study is to find a suitable location for rubber wood-based power plant, that involves complex decision making. Analytic Hierarchy Process (AHP) discovered by Saaty in 1977 [24] is a function based MADM method, which offers a sophisticated approach to solve decision-making problem. As standard protocol of AHP the goal was established i.e. to identify suitable spots for rubber wood-based power plant, then criteria were established, which were then compared in a pairwise matrix (1) and hence the weights were calculated, the consistencies among the judgment were checked, as a consistency ration should be less than 0.10 during AHP weight computation (see table 2).

$$\boldsymbol{M_b} = \begin{pmatrix} c_{11} & c_{12} & \cdot & \cdot & c_{1n} \\ c_{21} & c_{22} & \cdot & \cdot & c_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ c_{n1} & c_{n2} & \cdot & \cdot & c_{nn} \end{pmatrix} \quad (1)$$

Where, $\boldsymbol{M_b} = |c_{ij}| \ \forall\, i, j = 1,2,\ldots,n$ for n criteria, where the inverse will be c_{ji} or $1/c_{ij} \ \forall\, i \neq j \text{ and } C_{ii} = 1$.

Table 2. Weights of the siting criteria and the consistency ratio for this study.

Goal/objective	Main Criteria	Sub-Criteria	Weight	Consistency Ratio
Biomass power plant siting	Environmental	Water bodies	0.197	0.0949 < 0.10
		Floodplains	0.252	
		Important places	0.090	
		Watershed	0.163	
		Land use	0.046	
	Socio-economic	Residential Buffer	0.090	0.0957 < 0.10
		Slope	0.053	
		Elevation	0.043	
		Main Roads	0.037	
		Distribution System	0.024	
		Sum =	1.000	

The weights processed as a result of AHP using experts-based scores were then utilized to create a thematic map for all the involved criteria in ArcGIS 10.2.0 tool. The individual map was superimposed using overlaying tool function in GIS at a common spatial resolution of 1:50,000. The identified areas were then categorized into "highly", "Moderately", "low" suitable and "restricted" areas, a tool which has been shown in results. However, one of the challenges was to find the required area to secure a feedstock for several years of operation to ensure the sustainable operation of biomass facilities and we are solving it as below.

2.4. Biomass of para rubberwood and the area needed to secure a feedstock and the distribution of rubber trees in the study area

The economic lives of rubber trees are between 25-30 years and 3-4% are annually cut down for replantation in Southern Thailand. And as according to [8], rubber trees of different age level have different biomass potential. Rubber trees between 4-12 years have biomass potential of 0.06-0.21 tons and that for between 16-20 years have biomass 0.27-0.46 tons and for old trees between 22-25 years have biomass potential of 0.79-0.83 tons. And normally a footprint of 21 sq. meter is required for an individual rubber tree for healthy growth [8]. In accordance with this information, the following equation (2) was developed to find the required area to secure a feedstock to operate a 9.5 MW biomass facility in Southern Thailand.

$$A_{fp/day} = \frac{M_p}{M_t} \times A_{fp/t} \tag{2}$$

M_p is the biomass required by 9.5 MW power plant (i.e. M_p = 350 t/day), M_t mass of the individual rubber tree (i.e. either young, middle or old rubber trees), where area footprint covered by individual rubber $A_{fp/t}$ which is equal to 3 m x 7 m = 21 sq. meter. Using this information an area needed to secure a feedstock for a single power plant was calculated in excel spreadsheet.

However, the exact distribution of the presently available para rubber tree in the study area according to their age level was unknown but the local forest administer confirms that majority of the rubber trees in the study area are above 20 years old. So, in this study we assumed that 50% rubber trees are Old (above 20 years), 25% are of middle age level (12-20 years) and the rest of 25% are young trees (less than 12 years). This estimated area for the individual power plant by utilizing equation (2) was coupled with the result of GIS analysis to find all the possible locations for rubber wood-based facilities in the study area. The calculation was carried in excel spreadsheet and the results are presented in the next section.

3. Results and discussion

This study considered environmental and socio-economic aspects, by considering 10 parameters in total. The weights of AHP are in Table and it shows the floodplains as the most influencing criteria. The study found that out of 13,941 km^2 study area only 39.6% (5,522 km^2) could qualify for the mapping for rubber wood-based power plant locations. Out of which 4,890 km^2 (35%), which was either highly or moderately suitable areas where most of the highly suitable areas exist in considered districts of Songkhla Province (see figure 1).

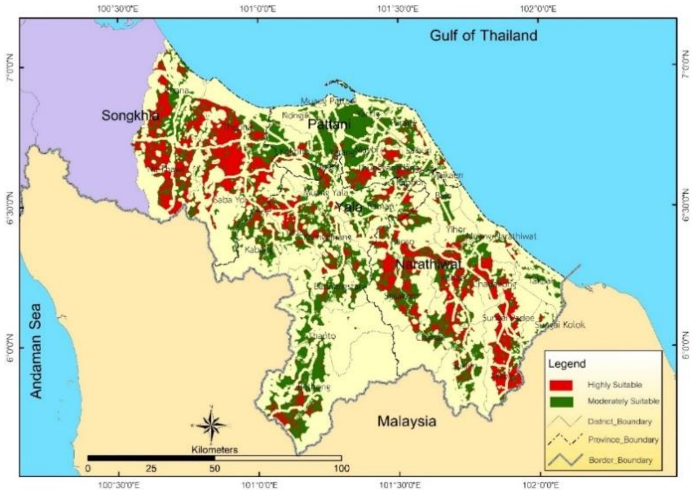

Figure 1. Highly and moderately suitable areas for rubber wood-based power plant.

Based on the assumptions it was found that 8 power plants of 9.5 MW individual capacity can be established in the study area with high suitability (see figure 2). Similarly, in moderately suitable areas, 13 para rubberwood-fired power plants could be established (see figure 3). And if combined both highly and moderately suitable areas then a total of 21 para rubberwood-fired power plants of 9.5 MW could be spotted in the study area (see figure 4). The power output calculated against these has also been presented in table 3.

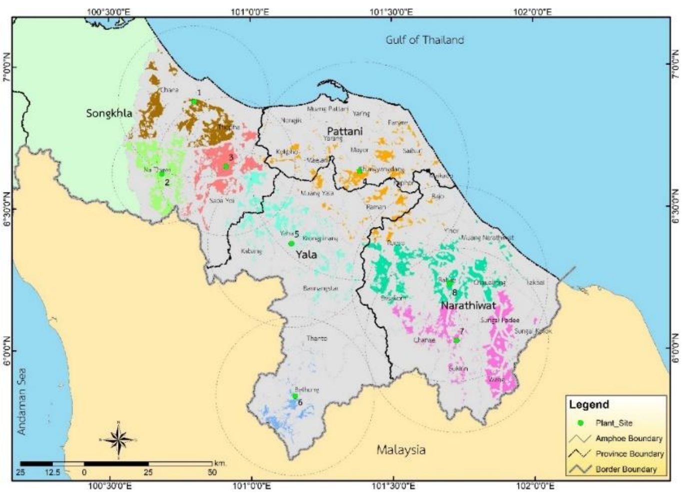

Figure 2. Power plant locations in the highly suitable areas

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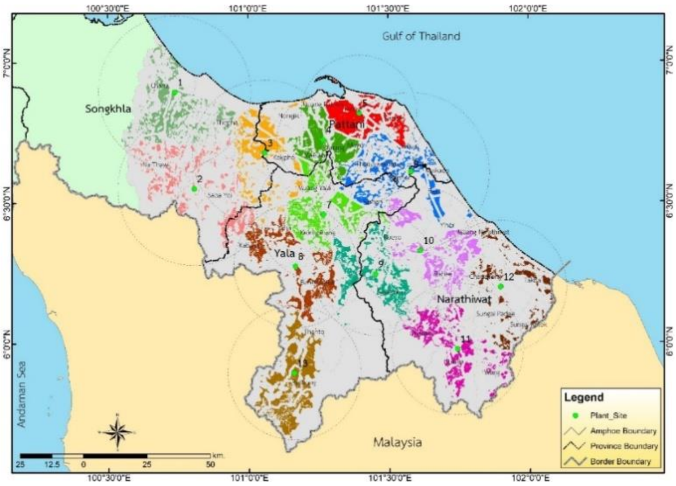

Figure 3. Power plant locations in the moderately suitable areas.

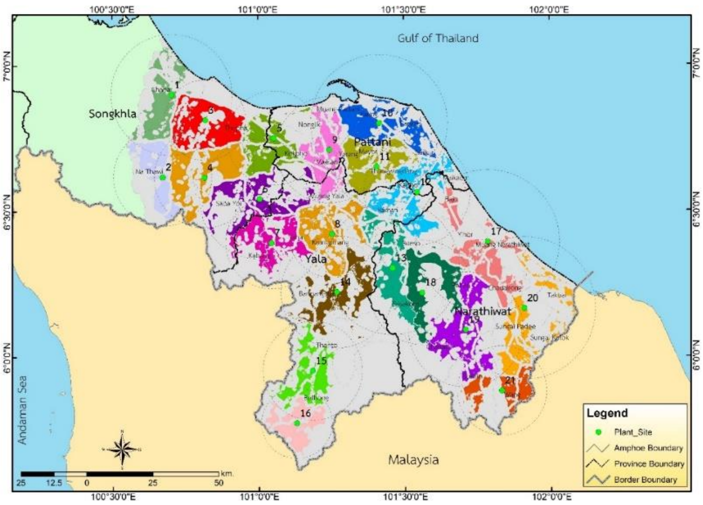

Figure 4. Power plant locations in both highly and moderately suitable areas.

Table 3. Power plants and their ananual energy production for the considered scenerios.

Scenarios	Density Type	No. of PP	PP capacity	Total Installed Capacity	Annual Energy Production
	O-M-Y (%)		(MW)	(MW)	(GWh/year)
HS area	50-25-25	8	9.5	76	602
MS area	50-25-25	13	9.5	123.5	978
HS and MS	50-25-25	21	9.5	199.5	1580

Key: O-M-Y = Old-Middle-Young; PP = Power Plant; HS = Highly Suitable, MS = Moderately Suitable

4. Conclusion

This study was conducted in the southernmost provinces of Thailand that provides a sophisticated approach to locate rubber wood biomass-based facility by taking into account both environmental and socio-economic choices. Expert's opinions were utilized to decide the importance level among the siting criteria and the weight computation was performed by using the AHP technique. Based on the computed weights, 10 thematic maps were produced in the GIS environment, which was then superimposed to get the final siting map. As per the findings of this study, most of the highly suitable areas were in four districts of Songkhla provinces. In total 21 spots were identified where biomass power plant using para rubber wood resource could be established. The findings of the study are likely to help the energy stakeholders in the region to take a serious considering on using para rubber wood for energy purposes.

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