EA001

Assessment of Power Generation Potential from Biomass Residues in Southern Thailand Using GIS Application and Electrical Substation Map

Pattaraanong KONGCHOUY[1]*, Warunee TIA[1], Adisak NATHAKARANAKULE[2] and Somchart SOPONRONNARIT[2]

[1]*Division of Energy Management Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi.*

[2]*Division of Energy Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi.*

Corresponding author: Pattaraanong KONGCHOUY. E-mail: aomjai.pattaraanong@gmail.com

Abstract

This research aimed to assess the potential of power generation from biomass residues in the southern Thailand using geographic information system (GIS), size of biomass collection area and electrical substation location. The biomass residue potential at 95% of total plantation area in the southern part, which can be used as feedstocks for power generation, were oil palm and coconut fronds; biomass from pruning of para-rubber, coffee, rambutan, and mangosteen trees and rice straw. Based on the percentage of unused biomass in the range of 25-100% or 718-2870 ktoe/y of the total biomass residues available in-field, the estimated power generation potential was in the range of 266 MW - 1063 MW. Among the seven crop residues, oil palm frond had the highest power potential of 74% of total, followed by coconut frond (12%) and rice straw (10%). The power generation in each collection area of 25kmx25km to 100kmx100km grid cell was also calculated and presented in the spatial distribution map. The potential of power capacity and electricity supply to the national electricity grid were identified based on the data of existing electrical substation location. Lack of substation in some grid cells reduced the power capacity to 46.2-931.6 MW, and the corresponding electricity that could be generated and transmitted through the national grid was 273,381 – 5,508,431 MWh/y.

Keywords: Geographic information system (GIS), Power generation potential, Southern Thailand.

1. Introduction

About 82% of the electricity supply in the country was produced by burning fossil fuels (Department of Alternative Energy Development and Efficiency, 2015), which had negative impacts on energy security due to their import dependency and GHG emission. Thus, the government had targeted to increase the electricity generation from renewable sources in the Alternative Energy Development Plan (AEDP: 2015). According to 52.7% of land use in Thailand was agricultural area (Kongchouy et al., 2016), therefore biomass from crop residues had a potential to be used as energy source for increasing power generation from renewable energy. The use of crop residues can decrease the fossil fuel imports, the risk of forest fires and GHG emissions (Fernandes and Costa, 2010).

Geographic information system (GIS) is a useful tool for assessing the biomass residue potential in a large geographical areas such as the research on the evaluation of biomass residue potential for energy production and utilization in Portugal (Fernandes and Costa, 2010), the assessment of dry residual biomass potential in the Party of General Pueyrredón, Argentina (Roberts et al., 2015) and the assessment of biomass residues potential from plantation areas in southern Thailand (Kongchouy et al., 2016). It can also be used for the spatial availability assessment of crop residue and the biomass power mapping in the Sonitpur district in India (Hiloidhari and Baruah, 2011). Moreover, GIS methodology can be applied for identification of the most suitable locations for power plant (Höhn et al., 2014).

Southern Thailand is a part of the country that has high electricity demand growth. In 2016 the electricity consumption in southern Thailand was 21,871x106 MWh, increased 5.94%from previous year (Provincial electricity authority, 2016). Most of agricultural residues from industries namely oil palm (fibers, shell and empty bunches), para rubber (sawdust, slab and root) and rice husk in the southern region were used as fuel for the heating processes and power generation. Thailand southern part has agricultural area of 26,404,282 rais, about 95% of which had total energy potential of 2,900 ktoe/y from crop residues namely rice straw, oil palm and coconut fronds, and branches of para-rubber, rambutan, coffee and mangoesteen (Kongchouy et al., 2016). Most of these residues still unused, therefore, this study aimed to assess the power generation potential from these crop residues and identify the potential of electricity supply to the grid based on the data of electric substation locations in the southern Thailand using GIS application.

2. Materials and Methods

The assessment of power generation potential from agricultural crop residues in southern Thailand using GIS application consisted of three main steps as shown in Figure 1: (i) assessing the power generation potential from overall unused crop residues in southern Thailand; (ii) calculating power potential on the various sizes of collection areas of crop residues; and (iii) preliminary assessing the potential of electricity supply to the national electricity grid based on the data of electric substation location in southern region.

2.1 Assessment of power generation potential from overall unused crop residues.

According to the previous research, the amount of energy available from 7 unused agricultural crop residues (rice straw, oil palm and coconut fronds, and branches of para-rubber, rambutan, coffee and mangoesteen) in southern Thailand was estimated by Kongchouy et al. (2016), which covered 95% of total agricultural area of 14 provinces, namely Krabi, Chumphon, Trang, Narathiwat, Nakhon Si Thammarat, Pattani, Phang Nga, Phatthalung, Phuket, Yala, Ranong, Songkhla, Satun and Surat Thani. The energy per rai of annual crop residues, as presented in the spatial distribution map in Figure 2, was used for assessing the power generation potential in this study. The power and electricity generation potential from crop residues in southern agricultural area was calculated using the following assumptions:

- Overall efficiency of thermal power plant using direct-fired boiler with steam turbine was 21% (Delivand et al., 2010).
- Operating hours per year of the power plant was assumed to be 6570 hrs/y based on the plant capacity factor of 75% (Delivand et al., 2010).
- 1 ton of oil equivalent is equal to 42.244 GJ (Department of Alternative Energy Development and Efficiency, 2015)
- The percentages of the available unused crop residues were considered in four scenarios, namely (a) 100%, (b) 75% (c) 50% and (e) 25% (Kongchouy et al., 2016). According to the farmer interview survey, the amount of crop residues was approximately 75% unused crop residue.

5) Own used electricity of power plant was 10% (Tangmanotieanchai et al., 2014).

Power and electricity generation were assessed by

$$P_{tot} = \sum_{i=1}^{n} \frac{EB_i \times 42.244 \times \left(\frac{UF_i}{100}\right) \times 10^6 \times \eta}{T \times 3600} \quad (1)$$

$$E_{elec} = P_{tot} \times T \times (1 - U_o) \quad (2)$$

where, Ptot was total power generation capacity (MW); EBi was amount of energy from available crop residues i (ktoe/y); η was overall efficient of the power plant (decimal); T was operating hours per year (hrs/y); UFi was unused residue factor of crop i (%); Eelec was the amount of annual electricity production (kWh/y); and UO was the percentage of own used electricity.

2.2 Calculation of power potential on the various sizes of collection area of crop residues.

The calculation of power potential from unused crop residues was conducted based on the collection areas of crop residues, called “grid cells”, which were considered in four area sizes, namely 25 km x 25 km, 50 km x 50 km, 75 km x 75 km and 100 km x 100 km. Power potential of 25-100% unused crop residues on each grid cells were calculated by using equation (2.1) and the energy distribution map (Figure 2).

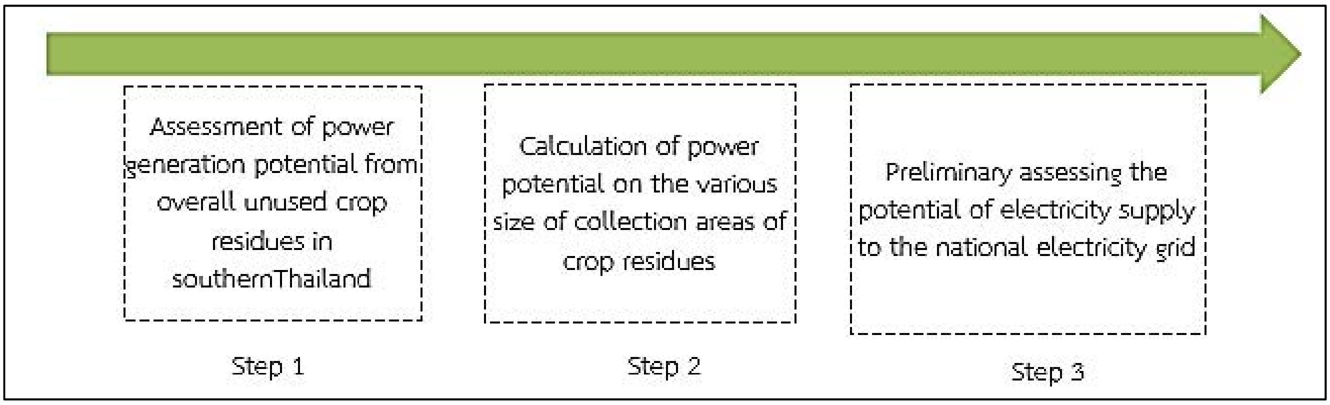


Figure 1 Steps of power generation assessment from agricultural crop residues in southern

2.3 Preliminary assessment of potential of electricity supply to the national electricity grid.

Currently, there are 34 electrical substations located in 14 provinces of southern region which were summarized in Table 1. The map of transmission lines and power substations in southern Thailand was constructed based on EGAT's data as shown in Figure 3. The generated electricity from available crop residues in each grid cell was estimated by using Eq. (2); and can be transmitted to the national electricity grid, by assumption, through the existing on-site substation located in the cell in case it was available as shown in the map of Fig. 3. Therefore, the total potential of electricity supply to the national electricity grid was finally identified.

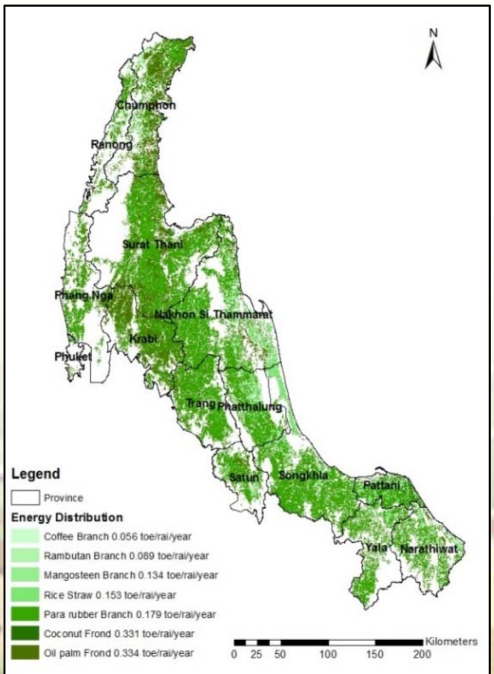


Figure 2 Energy distribution map of available crop residues in the southern Thailand. (Kongchouy et al.,

Table 1 Electrical substation in the provinces of southern Thailand.

No.	Substation Name	Code	Province
1	Ban Don	BDN	Suratthani
2	Bang Lang	BLG	Suratthani
3	Chum Phon	CP	Chum Phon
4	Chuping	CPNG	Songkhal
5	Hat Yai1	HY1	Songkhal
6	Hat Yai2	HY2	Songkhal
7	Khanom	KN	Nakhon Si Thammarat
8	Khlong Ngae	KNE	Songkhal
9	Krabi	KA	Krabi
10	Lam Phura	LR	Trang
11	Lang Suan	LSN	Chum Phon
12	Nakhon Si Thammarat	NT	Nakhon Si Thammarat
13	Narathiwat	NW	Narathiwat
14	Pattani	PTN	Pattani
15	Phang Nga	PN	Phang Nga
16	Phatthalung	PU	Songkhal
17	Phuket 1	PK1	Phuket
18	Phuket2	PK2	Phuket
19	Phuket3	PK3	Phuket
20	Phun Phin	PP	Suratthani
21	Ranong	RN	Songkhal
22	Ranot	RA	Songkhal
23	Ratchaprapha	RPB	Suratthani
24	Sadao	SDO	Songkhal
25	Satun	STU	Satun
26	SCG	SCG	Nakhon Si Thammarat
27	Song Khla	SKL	Songkhal
28	Songkhla2	SKL2	Songkhal
29	Su Ngai Ko Lok	SUK	Narathiwat
30	Suratthani	SRT	Suratthani
31	Takua Pa	TP	Phang Nga
32	Thung Song	TS	Nakhon Si Thammarat
33	Yala1	YL1	Yala
34	Yala2	YL2	Yala

Source: Electricity Generating Authority of Thailand (EGAT)

3. Results and Discussion

3.1 Power generation potential from overall unused crop residues.

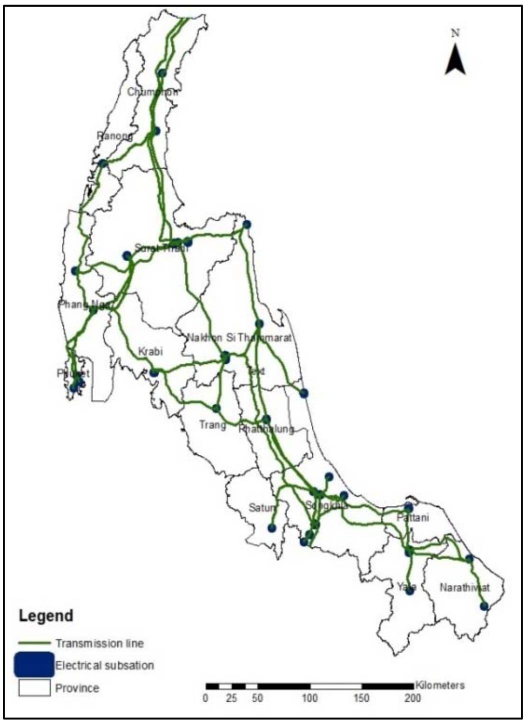


Figure 3 Map of transmission lines and power substations in southern Thailand.

The results of power generation potential from each 7 crop residue types (rice straw, oil palm and coconut fronds, and branches of pararubber,rambutan, coffee and mangoesteen) in the 95% agricultural area of southern Thailand were summarized in Table 2. Total of available energy of 100% and 25% of unused residues were 2869.9 ktoe/y and 717.5 ktoe/y, of which can be generated the power of 1,062.5 MW and 256.6 MW, respectively. More than 96% of total power potential was generated from oil palm fronds (74%), coconut fronds (12%) and rice straw (10%). The branch residues of para-rubber, rambutan, coffee and mangosteen cultivation area had low power potential. Oil palm fronds had the highest power potential, even though its cultivation area was only 16.6% of the total agricultural area in the southern region. In addition, oil palm fronds are available throughout the year, since the fronds are regularly cut during the harvesting of fresh fruit bunches (Tangmanotieanchai et al., 2014). According to high quantity of oil palm frond per unit area and regularly yield throughout the year, it is interesting to be used for increasing power generation from biomass. Rice straw and the branches of para-rubber, rambutan, coffee and mangosteen were seasonal availability based on the rice harvest season and pruning brunch period (Kongchouy et al., 2016), which required the management of feedstocks for power generation.

3.2 Power potential on the collection areas of crop residues.

The results of power potential on the collection areas (grid cells) based on the 75% unused crop residues for power plants in southern region were shown in Figure 4 and Figure 5. According to the collection area of (a) 25km x 25km grid cell, (b) 50km x 50km grid cell, (c) 75kmx75km grid cell, and (d) 100kmx100km grid cell, the southern region had grid cell number and the range of power potential per cell as (a) 163 cells and 0.01-30 MW, 44 cells 0.01-70 MW, 23 cells and 0.01-80 MW and 18 cells and 0.01-121 MW, respectively. Figure 4 showed the number of grid cells in each range of power potential. When expanding the size of collection area, the total number of grid cells were reduced, while the power capacity per grid cell was increased such as the scenario of the largest collection area of 100kmx100km grid cell.. Figure 5 showed the spatial distribution of power potential in each grid cell, of which depended on the amount of crop residues.

3.3 Potential of electricity supply to the national electricity grid.

To identify the potential of electricity supply to the national electricity grid, the spatial distribution map of power potential of 75% unused crop residues were overlays with the map of transmission lines and substations in southern Thailand, which were presented based on the collection areas of 25km x25km grid cell, 50km x 50km grid cell, 75km x 75km grid cell and 100km x 100km grid cell as shown in Figure 5 (a-d). The cell that had the substation located within it had potential to supply the generated electricity to the National grid. Based on the criteria, the results of preliminary assessment on the potential of power and electricity supply to the nation grid were summarized in the Table 3. The total power and electricity supply to the national grid were 46.2 MW and 273,381 MWh/y for 25kmx25km grid cell with 25% unused crop residues and 931.6 MW and 5,508,431 MWh/y for 100kmx100km grid cell with 100% unused crop residues. For the unused crop residue of 75%, the southern region had maximum power and electricity supply potential in the range of 698.7 MW and 4,590,481 MWh/y, respectively.

Table 2 Energy and power generation potential from biomass residues in agricultural areas of southern Thailand.

Unused	Oil palm frond		Para-rubber branch		Coconut frond		Rice straw		Rambutan branch		Coffee branch		Mangosteen branch		Total	
(%)	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW	ktoe y^{-1a}	MW
100	2105.5	789.6	59.5	21.2	361.1	128.9	291.8	104.2	24.3	8.7	22.5	8.0	5.2	1.9	2869.9	1062.5
75	1579.1	592.2	44.6	15.9	285.8	102	241.9	86.3	18.2	6.5	16.9	6.0	3.9	1.4	2190.4	810.3
50	1051.8	394.4	29.7	10.6	181.1	64.6	145.9	52.1	12.1	4.3	11.2	4.0	2.6	0.9	1434.4	530.9
25	526.4	197.4	14.9	5.3	90.3	32.2	72.9	26	6.1	2.2	5.6	2.0	1.3	0.5	717.5	265.6

[a] Source:(Kongchouy et al., 2016)

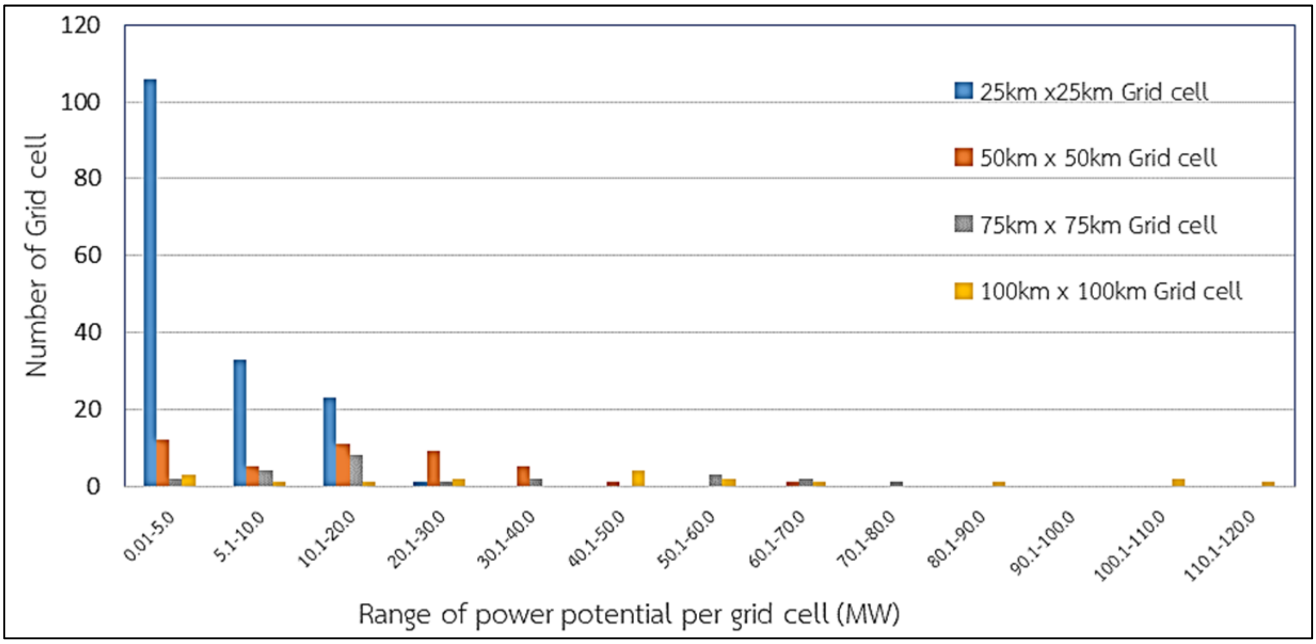
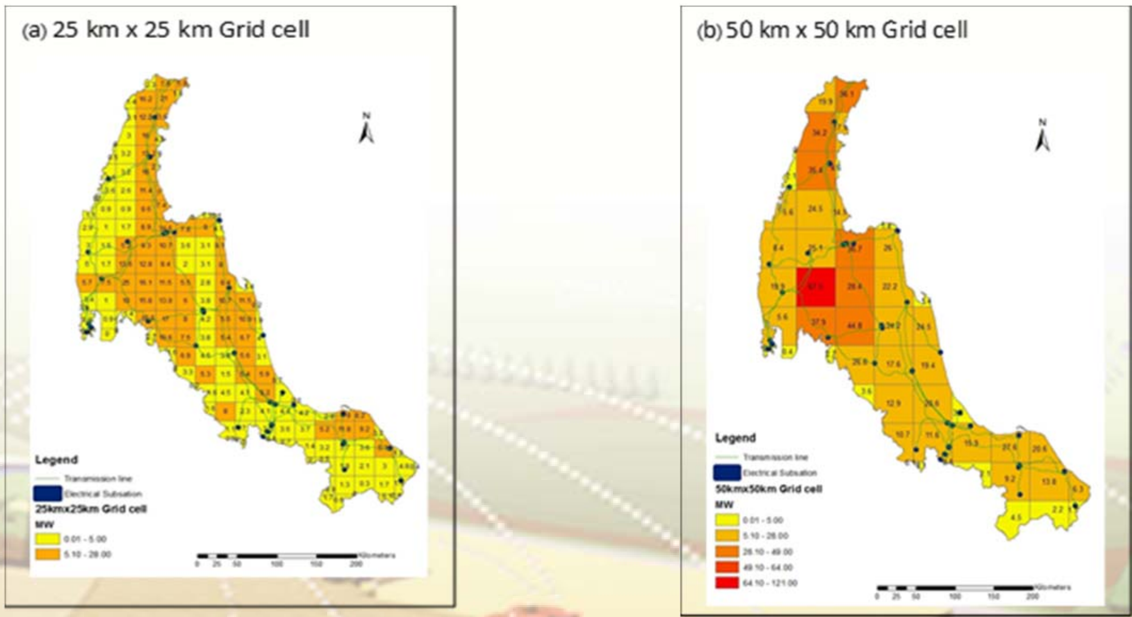


Figure 4 Power potential in the level of grid cell at 75% unused crop residues.



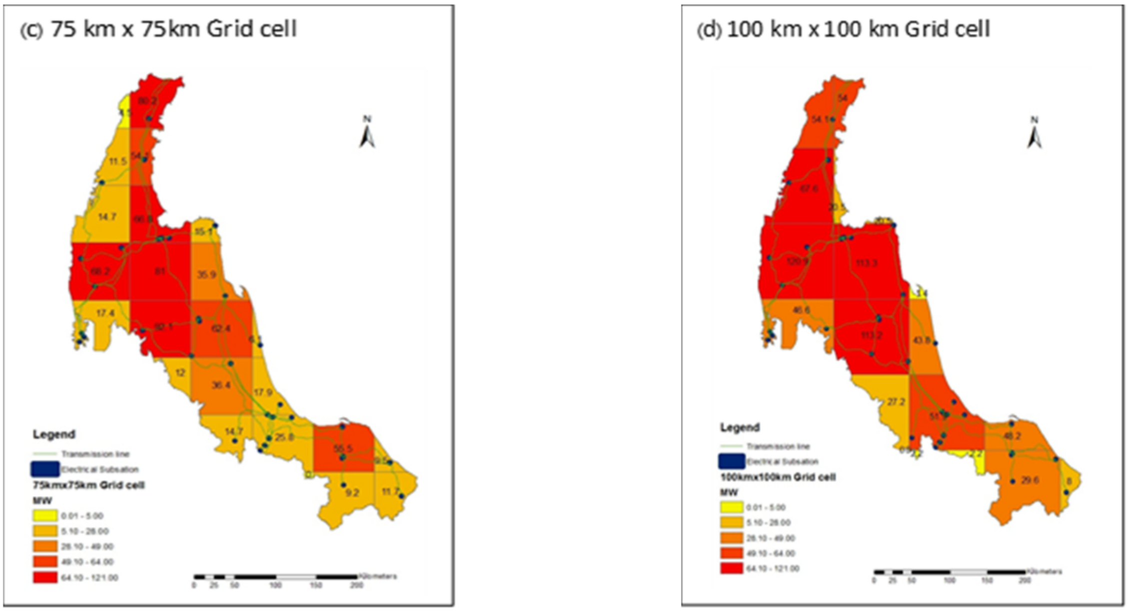


Figure 5 Spatial distribution map of power generation potential of 75% unused crop residues, transmission lines and substations in southern Thailand for the collection areas: (a) 25km x25km grid cell, (b) 50km x 50km grid cell, (c) 75km x 75km grid cell and (d) 100km x 100km grid cell.

Table 3 Potential of biomass energy, power capacity and electricity supplied to the grid based on size of grid cell and percentage of unused crop residues in southern Thailand.

Size of Grid Cell (km^2)	Unused crop residues											
	25%			50%			75%			100%		
	ktoe y^{-1}	MW	MWh/y	ktoe y^{-1}	MW	MWh y^{-1}	ktoe y^{-1}	MW	MWh y^{-1}	kltoe y^{-1}	MW	MWh y^{-1}
25x25	123.3	46.2	273,381	246.7	92.5	546,982	370.1	138.8	911,758	484.5	181.7	1,074,216
50x50	380.4	142.6	843,400	760.8	285.3	1,687,020	1141.3	428.0	2,811,822	1521.6	570.6	3,374,040
75x75	620.0	232.5	1,374,804	1240.4	465.2	2,750,486	1860.7	697.8	4,584,386	2480.9	930.4	5,501,191
100x100	621.0	232.9	1,376,998	1242.1	465.8	2,754,216	1863.2	698.7	4,590,481	2484.2	931.6	5,508,431

4. Conclusions

The power and electricity supply potential from the crops residues in 95%of southern agricultural area in Thailand were assessed using GIS based-approach and electrical substation map. The total maximum power generation from 25%-100% unused crop residues (rice straw, oil palm and coconut fronds, and branches of para-rubber, rambutan, coffee and mangoesteen) were in the range of 266 MW-1063 MW. Among seven types of crop residues, oil palm frond had the highest potential about 74% of the total power generation followed by coconut frond (12%) and rice straw (10%). In addition, oil palm frond is regularly available residue throughout the year and has high quantity of biomass per unit area. The power generation from 25%-100% unused crop residues were calculated based on the collection areas of 25kmx25km, 50kmx50km, 75kmx75km and 100kmx100km grid cells. According to the data of transmission lines and electrical substations of EGAT and 75% unused crop residues, the maximum potential of power and electricity supply to the national grid was 698.7 MW and 4,590,481 MWh/y, respectively, which was equal to 12.5 % of AEDP target for biomass power generation in 2036 and was only 0.02 % of its electricity demand in 2016.

5. Acknowledgements

The authors would like to acknowledge Electricity Generating Authority of Thailand for providing the data of transmission lines and electrical substations. Financial support provided by Thailand Research Fund (Grant No. DPG5980004) is gratefully acknowledged.

6. References

Delivand, K.m., Barz, M. and Gheewala, S.H.2011.Logistics cost analysis of rice straw for biomass power generation in Thailand, Journaol of Energy 36, 1435-1441.

Department of Alternative Energy Development and Efficiency (DEDE). 2015. Energy Balance of Thailand 2015(preliminary). Available at: http://www.dede.go.th/-download/ state_59/ Energy% 20Balance% 20of% 20-Thailand2015.pdf. Accessed on 10 July 2016.

Energy Balance of Thailand 2015. Availableat:http://www.-dede.go.th/download/state_59/Energy%20Balance%20of%20Thailand2015pdf.

Fernandes, U., Casta, M. 2010. Potential of biomass residues for energy production and utilization in region of Portugal. Biomass and Bioenergy 34, 661-666.

Hiloidhari, M., Baruah, D.C. 2011. Crop residue biomass for decentralized electricity power generation in rural areas (Part 1): Invsetigastion of spatial avialbility. Renewable and sustainable energy reviews 15, 1885-1892.

Hohn, J., Lehtonen E., Rasi, S., Rintala, J. 2014. A Geographical Information system (GIS) based methodology for determiniation of potential biomasses and sites for biogas plants in souther Finland. Applied Energy 113, 1-10.

Kongchouy, P., Tai, W., Nathakaranakule, A., Sopongronnarit, S. Assessment of biomass residues potential from plantation areas in southern Thailand using GIS. Proceeding of the nineth Thai socities Agricultural Engineering (TSAE) International Conference, 14-19. Bangkok, Thailand. 8-16 September 2016, Bangkok, Thailand.

Ministry of Energy. 2015. Alternative Energy Development Plan: AEDP2015. Available at: http://www.eppo.go.th-/images/POLICY/ENG/AEDP2015ENG.pdf. Accessed on 20 July 2016.

Roberts, J.J., Cassula M.A., Prado, O.P., Dias, A.R. 2015. Assessment of dry residual biomass potential for use as alternative energy source in the party of General Pueyrredon, Argentina. Renewable and sustainable Energy Reviews 41, 568-583.

Smart PEA annual report. provincial electricity authority:2016. Available at: https://www.pea.co.th/Portals/0/-Document/ AnnualReport/ TH_Annual_Report_2560. pdf. Accessed on 1 July 2016.

Sawangphol, N., Pharino, C. 2011. Status and outlook for Thailand's low carbon electricity development. Renewable and sustainable Energy Reviews. 15, 564-573.

Tangmanotieanchai, S., Tai, W., Soponronnarit, S. 2014. Feasibility Study of Using Oil Palm and Coconut Fronds for Electricity Generation.Journal of Research and Development King Mongkut's University of Technology Thonburi 37, 199-213.