GIS Approach for the Feasible Study of Biogas Plant from Cow Manure of Lumphayakang Dairy Cooperative in Thailand

Rakpong Saikaew, Woraratana Pattaraprakorn and Pornrapeepat Bhasaputra

Abstract— *The Geographic Information System (GIS) was proposed to indicate the feasible location of biogas plant from cow manure in the area of Lumphayakang Reform Land Dairy Cooperative, Saraburi Province, Thailand which consists of 8,570 dairy cows from 796 farms. The criteria to select feasible locations of biogas plant were proximity in biogas usage, convenience for transportation, constraints of social communities and consideration of environmental impacts. The analytical results showed that the feasible locations of biogas plants were Baan Lam Sum Pung, Baan Sab Ta Kong and Baan Kong Muang Nuea. In addition, all three locations were compared the financial indices that were a net present value (NPV), an internal rate of return (IRR), a benefit cost ratio (B/C) and a payback period (PB). The costs of biogas plant including transportation cost of cow manure, operating and investment cost, and the benefits of biogas plant including biogas using instead of liquid petroleum gas (LPG), fertilizer and the reduction amount of carbon dioxide in term of carbon credit were focused. The results of financial analysis showed the optimal location is at Baan Sab Ta Kong with NPV, IRR, B/C and PB of 3,717,595 Baht, 48.81%, 1.64 and 1.45 years, respectively. Furthermore, the waste utilization of cow manure to produce biogas can be converted to 5,298.29 ton of* CO_2 *per year which are approximately 3,973,721 Baht. Finally, the optimal management of dairy cow manure will enable the potential of energy from biogas up to* 10.9×10^6 *MJ per year in Thailand and* 68.7×10^6 *MJ per year in Greater Mekong Sub-region (GMS) as well as the potential of* CO_2 *reduction can be evaluated up to* 629×10^3 *ton of* CO_2 *per year in Thailand and* $3{,}962 \times 10^3$ *ton of* CO_2 *per year in GMS.*

Keywords— **GIS, Biogas, Cow Manure, Thailand.**

1. INTRODUCTION

According to Thailand's 15-year renewable energy development plan (2008-2022), the target of Thai government is to increase a share of the alternative energy to 20% of the country final energy consumption in the year 2022. The plan is divided into 3 periods: short term (2008-2011), mid term (2012-2016) and long term (2017-2022). Short term strategy is to emphasize on promotion of commercial alternative energy technologies and high potential energy sources such as biofuels, biogas, and cogeneration from biomass with fully support from standard measures provided. As for mid term strategy, the plan focuses on development of alternative energy technology industry, encourage new alternative energy research and development to achieve economic viability including new technologies for biofuels production and introduce a model development of Green City to communities for sufficient economy and sustainable development. Finally, long term plan is to enhance utilization of new available alternative energy technologies such as fuel cell, bio-hydrogenated (BHD), to extend green city modes throughout Thai communities and to encourage being hub of biofuels and alternative technologies export in ASEAN. The objectives of the alternative energy plan for the long term fifteen year are to replace import fossil fuel with alternative energy as a major energy supply to the country, to strengthen the security of energy provision, to promote using the green energy, to enhance alternative energy technology industries and to research and encourage high efficiency alternative energy technologies. The goal of the plan is to develop the energy infrastructure which leads to the sustainable energy. Biogas plays as one of the important keys of the alternative energy for both electrical and thermal sources. The potential for electrical generation from biogas is 190 MW within 2022, while the existing power plants are only 29.2 MW or 15.37% of target. Likewise, the potential for thermal generation from biogas is 470 ktoe while the current usage is about 79 ktoe or 16.81%. According to the medium term planning in between 2006 to 2011, it has focused on the biogas production from pig farms and industrial wastewater treatment with the targets of supplying to electrical and thermal purposes in 2011 are 60 MW and 370 ktoe, respectively [1].

Biogas is a product from anaerobic digestion of organic substances which are usually sewage, animal manure or agricultural waste. The waste utilization is a key point of clean technology to balance between the environmental management and business management. A multi-scenario method is proposed to enhance the waste management, that optimal scenario is selected based on the decision-making. Finally, the environmental friendly concept is

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considered to evaluate the additional benefit. However biogas from the 15-year renewable energy development plan is not included the potential from cow manure in dairy farms.

Data from Department of Livestock Development in 2007[2], there were 489,593 dairy cows in Thailand and the highest quantities were found at Saraburi province, detailed in Fig.1. Therefore, cow manure from dairy farms is one of the interesting feedstock of biogas production. In general, a cow has a potential to produce biogas 0.75 cubic meters and the overall potential of biogas from cow manure in Thailand can approximately be 587,512 kWh in term of electrical generation. The efficiency of biogas utilization is illustrated in Table 1. Most of dairy farms in Thailand are small to medium sizes under the operation of cooperatives, therefore; the site to collect manure and install biogas plant has to be carefully considered. The potential of biogas from dairy cow manure in Thailand can increase biogas potential utilization in term of totally thermal energy or totally electrical energy at 10.9×10^6 MJ and 587,512 kWh, respectively. Furthermore, the optimal biogas management can enable the potential of thermal energy and electrical energy up to 68.7×10^6 MJ and 3,701,250 kWh in Greater Mekong Sub-region (GMS).

Optimal location of biogas plant affects to the economic evaluation of the biogas operation. Many researchers focused on the determination of the optimal location of renewable energy plants. In [3], the costs of biogas and electricity production from maize silage in relation to plant size were investigated. Transportation cost was an influence factor to the cost-effective plant size. The costs decreased when biogas plant with larger size and proximity to the feedstock were established.

Geographical information system (GIS) is a tool to integrate maps with database to produce geographical information. GIS-based application has been widely used for biomass-availability estimation, selection of a suitable route and a decision-making process for locating wind farm sites. It was used to select least-cost bioenergy location in Northern Spain [4]. Biomass delivery cost is decreased when the plant’s capacity is small thus the maximum distance from the energy unit should be arranged. In [5], to achieve optimal use of agricultural and forest residue biomass, logistics and transportation strategies had to be developed. GIS was used to combine the information of biomass residue, environmental and social constraints. Moreover, the optimal sites of anaerobic digester system for distributed generation were investigated by GIS technique with a case study of Tompkins County, New York [6]. The results were directly supported to local government, electric utilities and farms to realize the energy potential and facilitate as a guide to utilize them.

Thus the objective of this study was to determine the optimal location of biogas plant by using GIS technique with considering to economic aspects with a case study of dairy farms under operation of Lumphayakang Reform Land Dairy Cooperative, Saraburi Province, Thailand.

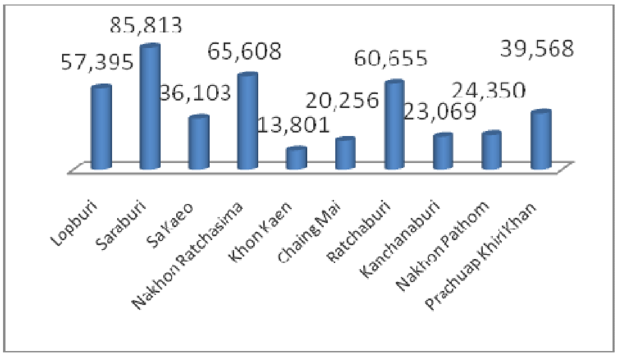


Fig.1. Number of dairy cows in Thailand

2. METHODOLOGY

The dairy farms in this study covered 2 provinces; Nakhon Ratchasima and Saraburi Province and 3 Tambons or sub-districts; Lamphaya Kang and Lamsumpung in Saraburi province and Jantuk in Nakhon Ratchasima province. In order to minimize the transportation cost, this study focused to the dairy farms with more than 20 dairy cows in the radiaus of 20 kilometers from cooperative office thus they consisted of 796 dairy farms and 8,570 dairy cows. The methodology of this study was summarized in Fig. 2.

Table 1 The potential of biogas conversion to various energy types

	No. of dairy cows	Biogas produced	Biogas produced equivalent to		
			LPG	Electricity	Diesel
		(m^3)	(kg)	(kWh)	(liter)
	1	0.75	0.46	1.20	0.59
Saraburi	85,813	64,360	39,474	102,977	50,630
Thailand	489,593	367,195	225,213	587,512	288,860
Laos PDR**	37,700	28,275	17,342	45,240	22,243
Cambodia**	140,000	105,000	64,400	168,000	82,600
Myanmar**	2,269,082	1,701,812	1,043,778	2,722,898	1,338,758
Vietnam**	148,000	111,000	68,080	177,600	87,320
GMS*	3,084,375	2,313,281	1,418,813	3,701,250	1,819,781

GMS* is including only Thailand, Laos PDR, Cambodia, Myanmar and Vietnam but not Yunnan Province and Guangxi Zhuang Autonomous region of the People’s Republic of China because of no adequate data.
** Data is from FAO (2008), http://faostat.fao.org

Quantities of cows were counted and the positions of dairy farms were identified by global positioning system (GPS). Map of road network, land use, forest area, water resource and other important places such as school, temple, hospital and village were collected from the database of government agencies [7-8]. The utilization of cow manure and amounts of LPG consumption from each dairy farm were identified by questionaire. All information was converted to digital format by using ArcGIS and integrateded by overlay technique as illustrated in Fig. 3. The social and environmental constraints accompanied with transportation limitation were specified with the criteria to select the feasible locations of biogas plant as follows [9]:

- Proximity to main road within 30 m
- Proximity to surface water within 50 m
- Proximity to community within 1000 m
- Prohibity to agricultural and forest area
- Further from sensitive areas such as temple, school and hospital

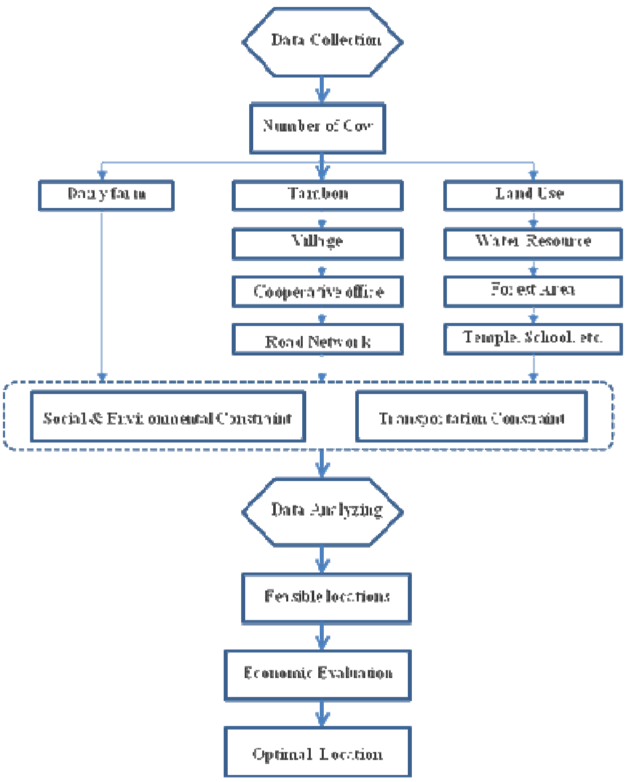


Fig. 2. Methodology overview

After feasible locations were identified, the potential of biogas production had to be determined. The potential was considered in both cases; either to produce the biogas sufficient for member of cooperatives, or to produce from overall feedstock. To achieve both cases, the size of biogas plants and quantities of cow manure in each location had to be calculated. In this study biogas plant used the fixed-dome digestion system. The profits of three feasible locations were evaluated. Costs of biogas plant composed of investment cost, operating and maintenance cost and transportation cost of cow manure to biogas plant while revenues were the benefit of using biogas instead of LPG, sludge of biogas plant sold as fertilizer and reduction of carbon dioxide considered as carbon credit.

With consideration of the project life of 15 years and discount rate of 8%, the financial indices that were a net present value (NPV), an internal rate of return (IRR), a benefit cost ratio (B/C), and a payback period (PB) of each feasible location were analyzed and compared to determine the optimal location of biogas plant.

In order to find the financial indices, the logistic cost, the volume of biogas from biogas plant and size of biogas power plant are determined. Firstly, the logistic cost can be calculated from equation (1).

$$LC_{tj} = \sum_{k=1}^{N} (b \times d_{jk} \times C_{jk} \times 7 \times 365) \tag{1}$$

where LC_{tj} is total logistic cost to deliver cow dung from farm to biogas plant j (Baht per year),
b is a constant logistic cost that is 0.02 Baht per kg per km per ,
d_{jk} is the distance between farm k and biogas plant j (km),
C_{jk} is the quantity of dairy cow in farm k considering of biogas plant j (cows) ,
N is numbers of farm (farms).

Note: A dairy cow produces 7 kg of dry manure per day [10].

According to the function of GIS program, the optimal route from a dairy farm to the biogas plant is evaluated based on data and resolution of road network which refer to the shortest distance.

Secondly, the volume of biogas from biogas plant j can be estimated as shown in equation (2).

$$BG_j = 0.75\sum_{K=1}^{N}(C_{jk} \times r) \tag{2}$$

where BG_j is the biogas volume (m^3),
r is the ratio of Methane in biogas volume which is about 60 %.

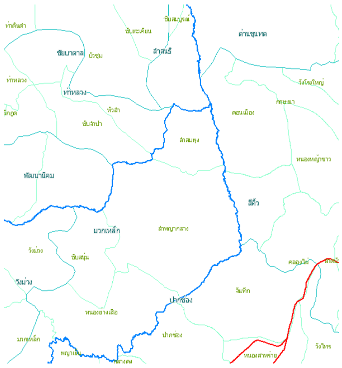
Note: A dairy cow produces 0.75 m^3 of biogas per day [10].

Thirdly, biogas plant size can be calculate from equation (3).

$$PS_b = Round\left(2 \times \frac{(W \times N_C \times RT)}{1000}\right) \tag{3}$$

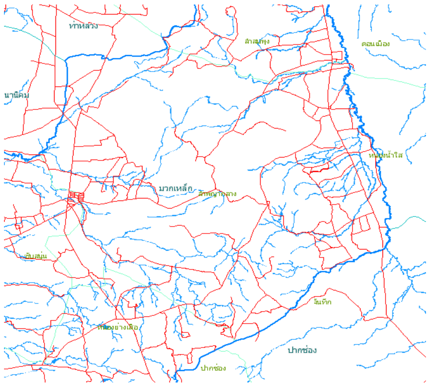
where PS_b is the biogas plant size (m^3),
W is the weight of fresh manure from a dairy cow per day (kg),
RT is the retention time (days),
N_c is the number of cow (cows).

A1) Map of provicial border

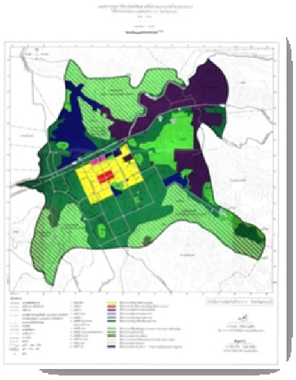


A2) Data processing of provincial border

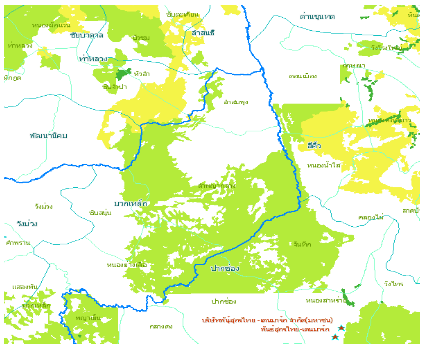
B1) Map of Road network



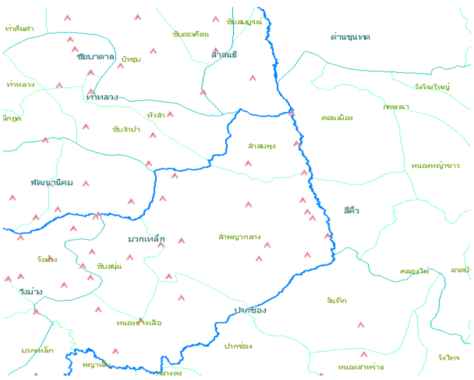
B2) Data processing of road network



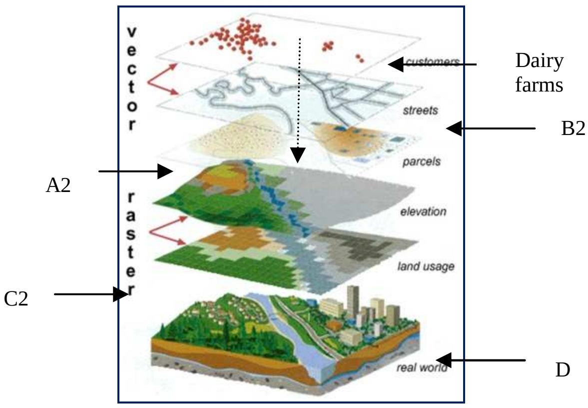
C1) Map of land use such as agricultural, forest area and water resources



C2) Data processing of land use



D) Map of community area such as temple, school, hospital, etc.



E) Overlay technique

Fig. 3. Data processing and overlay technique.

Note: From experimental results, the weight of dairy cow dry manure is around 50% of dairy cow fresh manure, the retention time of fixed dome is approximately 60 days, and a constant of biogas plant installation is 2 m^3/ton [11 and 12].

Forthly, the revenue from biogas plant *j* for LPG substitution (LPG_{Rj}) can be calculated as shown in equation (4).

$$LPG_{Rj} = 1{,}435.55 \times \sum_{k=1}^{N} C_{jk} \quad (4)$$

Note: A constant of biogas revenue to substitute LPG from one cow is 1,435.55 Baht/year [10].

Then, the fertilizer revenue from biogas plant *j* (F_{Rj}) can be determined from equation (5).

$$F_{Rj} = 82.125 \times \sum_{k=1}^{N} C_{jk} \quad (5)$$

Note: A constant of fertilizer revenue as biogas by-product generation from one cow is 82.125 Baht/year [10].

Finally, the revenue of carbon reduction from biogas plant *j* (CC_{Rj}) can be calculated from equation (6).

$$CC_{Rj} = 923.906 \times \sum_{k=1}^{N} C_{jk} \quad (6)$$

Note: A constant of carbon credit revenue from the amount of CH_4 and CO_2 that can be reduced in biogas plant *j* from a cow is 923.906 Baht/year.

3. RESULTS AND DISCUSSION

Area of this study is the central part of Thailand which is a high intensity of dairy farms. Most of dairy farms in Thailand are under the operation of cooperative in order to strengthen the negotiation power of dairy farms in the small to medium sizes. Size distribution of dairy farm in this study is illustrated in Table 2. Most of dairy farms (about 70%) are small size about 20 to 30 cows a farm and the larger one more than 50 cows. Cow manure management was also surveyed by questionnaire. About 59 percent of cow manure is used as a fertilizer in the owner area, 30 percent is sold as a fertilizer, 6 percent is disposed and the remaining of 5 percent is sold as an animal feed.

Table 2. Size distribution of dairy farms in this study

No. of cow	No. of dairy farm	%
20-30	60	37.5
30-40	32	20.0
40-50	9	5.0
More than 50	59	37.5

After combining the various types of map with the position of dairy farms, the criteria to select the feasible locations of biogas plant had to be considered. From GIS analyzing, there were three feasible locations; Baan Lam Sum Pung, Baan Sab Ta Kong and Baan Kong Muang Nuea (Fig.4). The potentials of biogas production were calculated from the number of dairy cows and the size of biogas plant in each location as depicted in Table 3. It found that the raw material to produce biogas has twice to the requirement of the members of dairy cooperative therefore the other options of biogas utilization should be concerned such as using biogas to produce electricity.

Economic evaluations of all three feasible locations of biogas plants were calculated. Investment cost is a function of plant size refered to data from Energy Policy and Planning Office, Ministry of Energy, Thailand [13]. Operating and maintenance cost of biogas plant were estimated and the transportation cost depended on the distance of dairy farm to the feasible location. Produced biogas was used in place of LPG relating to the LPG consumption of dairy farms thus the revenue can be calculated from the benefit. Sludge from biogas plant can be sold as a high quality of fertilizer. Moreover, in case that the reduction of CO_2 can be certified as carbon credit, it can be traded at the rate of 750 Baht/ton CO_2 equivalent. The optimally placed biogas plant reduces the CO_2 about 5,298.29 Ton per year.The overall of cost and revenue of biogas production are summarized in Table 4 and the financial indices of all feasible locations of biogas plant are evaluated in Table 5.

Table 3 Potential of biogas production in three feasible locations

Location	No. of dairy farm	For member		All potential	
		No. of cow	Plant size (m^3)	No. of cow	Plant size (m^3)
B. Lam Sum Pung	41	1,042	2,000	2,312	4,000
B. Sab Ta Kong	41	1,042	2,000	1,957	4,000
B. Kong Muang Nuea	78	1,983	4,000	4,301	8,000

From analysis cost and revenue, the biogas plant at Baan Sab Ta Kong revealed the lowest transportation cost compared to the other feasible locations because it is the closest location to the feedstock of biogas plant. While the other costs and revenues related to the size of biogas plant and the potential of biogas production. In case of considering the potential of biogas plant for the member of cooperative, the location of biogas plant at Baan Sab Ta Kong indicated the highest profit in all financial indices whereras in case of that for the all potential, the location at Baan Lam Sum Pung revealed the higher profit especailly in term of NPV, IRR and PB as shown in Table 5. Furthermore, the completed results of this study will be considered as part of cooperative's decision on project analysis of biogas plant at Lumphayakang Reform Land Dairy Cooperative area.

Table 4 The overall cost and revenue of three feasible locations of biogas plant

	Biogas produced (m^3)	Cost of biogas plant (Baht)			Revenue of biogas plant (Baht)		
		Investment cost	Operating cost	Transportation cost	LPG substitution	Fertilizer	Carbon credit
For member							
B. Lam Sum Pung	285,247	1,736,075	10,000	613,565	1,495,838	85,574	962,710
B.Sab Ta Kong	285,247	1,736,075	10,000	490,620	1,495,838	85,574	962,710
B. Kong Muang Nuea	542,846	3,442,725	10,000	2,030,459	2,846,686	162,854	1,832,106
All potential							
B. Lam Sum Pung	632,910	3,442,725	10,000	1,361,384	3,318,980	189,873	2,136,071
B. Sab Ta Kong	535,729	3,442,725	10,000	921,442	2,809,362	160,719	1,808,085
B. Kong Muang Nuea	1,177,399	6,856,025	10,000	4,403,891	6,174,279	353,220	3,973,721

Table 5 The economic evaluation of of three feasible locations of biogas plant

Location of biogas plant	NPV (Baht)		IRR (%)		B/C		PB (Year)	
	For member	All potential	For member	All potential	For member	All potential	For member	All potential
B. Lam Sum Pung	2,871,275	7,437,887	40.98	48.53	1.42	1.47	1.78	1.34
B. Sab Ta Kong	3,717,595	6,875,079	48.81	45.70	1.64	1.58	1.45	1.62
B. Kong Muang Nuea	2,652,687	6,464,372	25.08	29.16	1.16	1.20	3.13	2.56

Table 6 The summary of biogas management in GMS

Location	Number of Cow	Biogas (m^3/day)	Thermal energy from biogas (MJ/day)	LPG substitute (Baht/year)	Fertilizer (Baht/year)	Carbon credit (Baht/year)	Carbon reduction (Ton of CO_2/year)
Thailand	489,593	367,195	10,911,210	702,835,231	40,207,825	471,713,064	628,951
Cambodia	140,000	105,000	840,192	200,977,000	11,497,500	134,887,200	179,850
Laos PDR	37,700	28,275	3,120,077	54,120,235	3,096,113	36,323,196	48,431
Myanmar	2,269,082	1,701,812	50,569,374	3,257,380,665	186,348,359	2,186,215,125	2,914,955
Vietnam	148,000	111,000	3,298,367	212,461,400	12,154,500	142,595,040	190,127
GMS*	3,084,375	2,313,281	68,739,220	4,427,774,531	253,304,297	2,971,733,625	3,962,314

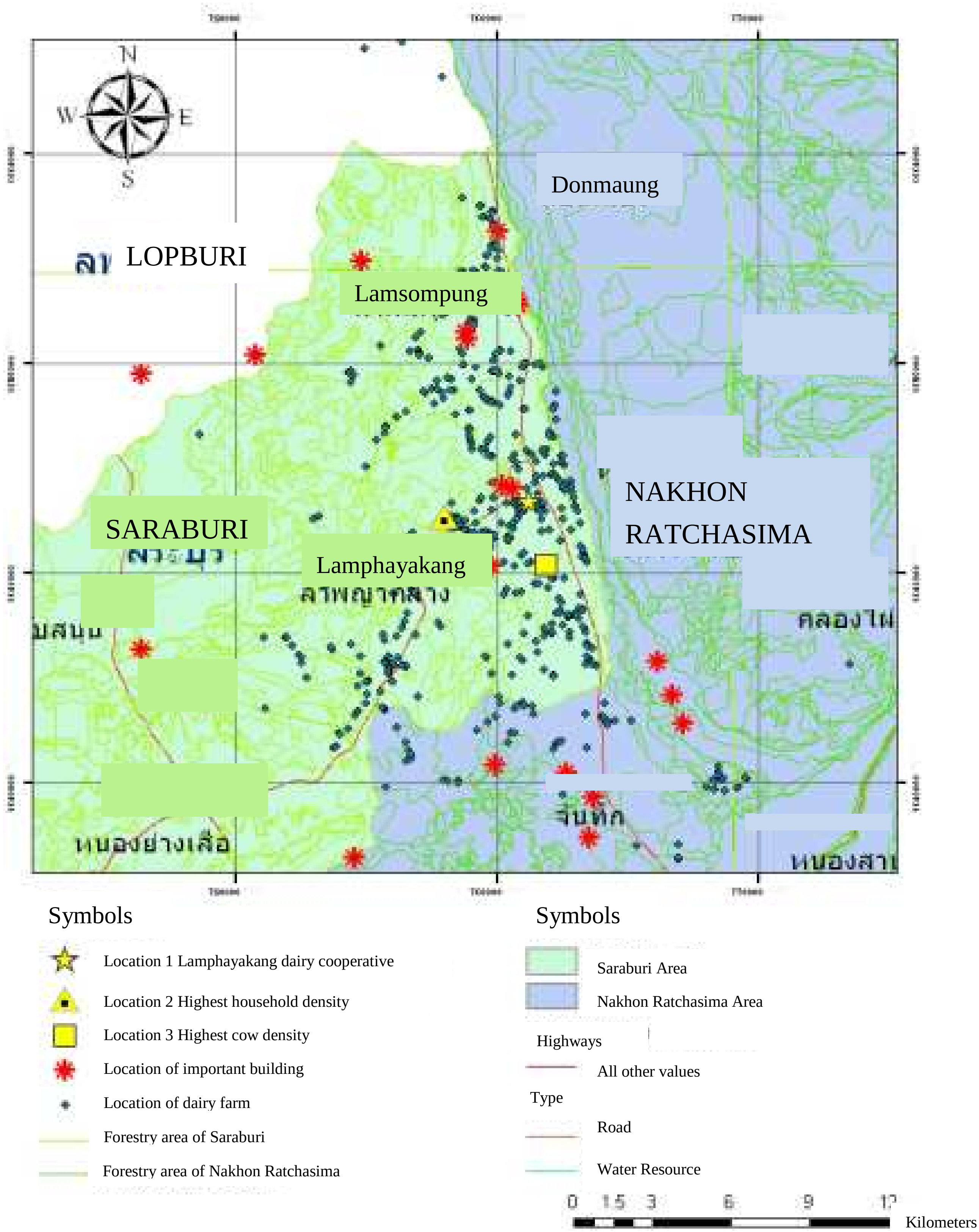


Fig. 4. The feasible locations of biogas plants

Finally, the summary of biogas management in GMS consisting of thermal energy production calculated in MJ, revenue from LPG substitution, fertilizer as well as carbon credit in Baht per year and carbon reduction in ton of CO_2 reduction are shown in Table 6.

The reduction of carbon dioxide (*RC*) can be estimated from equation (7).

$$RC = 1.285 \times N_c \quad (7)$$

Note: the constant of the annual CO_2 reduction per cow that is 1.285 (Ton of CO_2 per year)

4. CONCLUSION

In this paper, the proposed GIS can enhance the performance to indicate the optimal location of biogas plant in term of minimum risk assessment and in depth of financial analysis. The more accurate analytical results with the lowest risk lead the cooperative to make a decision for investment of biogas plant. The effective policy planning from the government can increase the efficiency of energy management. In Thailand, the energy of biogas from dairy cow manure has the potential up to10.9×10^6 MJ. Furthermore, the potential of dairy cow manure in GMS can replace the fossil fuel up to 0.8×10^6, 3.1×10^6, 50.6×10^6, $3.3\times10^6$and 68.7×10^6 MJ in Cambodia, Laos, Myanmar, Vietnam and GMS that not included Yunnan province and Guangxi Zhuang autonomous region of the People's Republic of China, respectively. While environmental benefit from CO_2 reduction has the potential when the biogas are implemented successfully up to 628,915, 179,850, 48,431, 2,914,255, 190,127, 3,962,314 Ton of CO_2 reduction in Cambodia, Laos, Myanmar, Vietnam and GMS that not included Yunnan province and Guangxi Zhuang autonomous region of the People's Republic of China consecutively. Finally, the biogas energy is the successive key point of renewable energy management to achieve the reduction of imported energy, to maximize social benefit and to minimize the environment impact from the conventional energy sources.

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