

Spatial mapping analysis for renewable energy agricultural water system of small community farm

Ratchada Kamching^a, Mechai Pattarapremcharoen^a, Songwut Nirunsin^b, and Worajit Setthapun^{a,*}

^a Asian Development College for Community Economy and Technology, Chiang Mai Rajabhat University, Chiang Mai, Thailand

^b Defence Energy Department, Defence Industry and Energy Center, Bangkok Thailand
Tel: +6653-885-871, Fax: +6653-885-871

*Corresponding author: worajit@gmail.com

Abstract

This research focused on the integration of spatial mapping analysis and renewable energy technology to determine the optimal water source and water distribution technique for a small community farm. The study area was the Smart Community farm of the Chiang Mai Rajabhat University, Thailand, which covers approximately one rai. The area is a representative of a remote agricultural land that needs a renewable energy based water system. It was found that a water system relying on a combination of groundwater with solar energy was the most appropriate to be used in the area, compared to other sources such as wind energy. This system was developed by installing a solar-powered groundwater pump to the groundwater well. This practical application could efficiently supply sufficient water for agricultural activities in the community. The format and the process of analyzing the area's potential in this research can be applied to develop an appropriate agricultural water system in a remote area with the absence of a power grid. The system can also be useful in reducing costs of energy or fuel. In order to use this approach effectively, the community must adjust the system to match the physical characteristics of its area. The potential of the area in terms of water sources and renewable energy sources will allow the community to have sufficient water and energy to use inside the community. The community will have security in water and energy sources without relying on unstable outside power sources.

Keywords: *Spatial mapping, solar energy, wind energy, GIS*

1. Introduction

Securing plant growth is the main goal of farmers, therefore, water is highly important for agricultural production. In some areas, water sources are limited and insufficient for plant cultivation. In Thailand, developed water sources that are beneficial to agriculture accounted for only 22 percent (about 30 million rai) of the total 132 million rai of agricultural according to the Department of Water sources [1]. The remaining 78 percent is the area outside the irrigation zone [1]. Thus, many farmers need to obtain water from other sources for farming. The criteria of the water source potential are the water quantity, quality, and yielding cost. Farmers generally need to pump water using electricity or fuel. Some of them need to draw water from a source far away from their farms, leading to higher production costs. In areas without electricity, farmers need to use costly diesel fuel for their water pumps. On the average, 1.19 liter of fuel is needed to pump 1 cubic meter of water. For cultivation of 1 rai, 10 m³ of water is needed per day [2]. That means the farmer needs to use 12 liter/day or 360 liter/month of fuel. Considering the average price of diesel oil at about 26 baht/liter in 2015 [3], the energy cost for water pumping is about 300 baht/day/rai or 9,000 baht/month/rai. The cost would be higher for a larger agricultural area.

Therefore, a water pumping system should be developed to serve farmers needs in remote areas where electricity from the power grid is not available. In addition, it should be powered by another energy

source in lieu of traditional fuel, which causes higher production costs to farmers presently. Recently, solar and wind power have been studied and used for water pumps instead of traditional fuel. The number of solar-powered pumping systems installed in Thailand is increasing gradually. By the end of 1994, there were a total of 426 solar-powered pumping stations being installed, which altogether had a maximum electrical power of 405 kW. The Department of Public Works and Town & Country Planning is the public organization that installed the highest number of such systems, and accounted for 72.8% of the total number of solar-powered water pumping systems in the country. Most systems were installed in the Northeastern region, and Nakhon Ratchasima is the province with the highest number of the systems [4]. At the end of the 2000, all the solar-powered pumping systems in Thailand had a total electrical power of 994 kW. The total power increased to about 1,500 kW at the end of the 2013 [5]. According to these figures, Thailand has an increasing trend to install solar-powered pumping systems. Relevant studies showed that the solar-powered pumping systems have been used in various projects to support communities in remote areas without electricity. These systems can pump water from either surface or underground water sources. These systems use solar cells to convert sunlight into electricity to drive the motor of a pump.

For the use of 14 panels of 125-watt solar cells, a water pump can take water from a source to supply an area being less than 6 meters above the pump for 100,000 liters per day. For the area that is about 40 meters above the water source, this configuration can supply water for agricultural use at 25,000 liters per day [6].

The points of concern in using solar-powered water pumping systems are the effectiveness and worthiness of the solar panels to be used with the pumps. A study of the appropriateness of a solar cell for water pumping systems according to the principle of Sufficiency Economy for agriculture revealed that the Flexible Solar Panel type was more efficient and provided the highest economic break-even point as compared to Poly Crystalline and the Amorphous Silicon types [7]. Currently, innovative water pumping machines that use a Solar Inverter Pump based on MPPT (Maximum Power Point Tracking) have been developed to reduce the cost even more. These machines can use solar energy more efficiently because its inverter can manage power by finding the point of maximum energy transfer in each light spectrum so that the machine can work best at certain light intensities. In addition, they have been designed to be used appropriately in various outdoor conditions [8]. A study investigated the efficiency of a solar-powered water pumping system that is based on the bubble pump technique. The technique was found to increase the efficiency of the water pumping system when being installed in a higher altitude without being affected by air pressure. Therefore, solar-powered water pumping systems with a bubble pump technique are suitable for highland farms in a remote area [9].

Besides solar power, wind power is also interesting for water pumping. Similar to a solar-powered system, a wind-powered water pumping system converts wind energy to electricity to be used for pumping water. A point of concern in implementing this system is wind speed in the area. Wind speeds vary according to topographic characteristics. In Thailand, on average, a 1 kW wind turbine for a water pumping system can produce about 300 W of electricity when the wind speed is 4.5 meter/second. It can bring water to an area up to 20 meters above the water source at 18,000 liters/day, with an efficiency of 45% [10]. It is important that the wind turbine should be designed to efficiently utilize the wind. Several research and development projects are continuously trying to develop wind turbines for water pumping. Prototypes of wind turbines for agricultural water pumping systems in communities have been developed both via researches institutions [11] and via succession of local wisdom [12].

In addition to the design of wind turbines, the location for installation also deserves attention. The installation location should be large, wide open, and windy most of the time. Seaside's are a good example of such areas suitable for wind turbines. But there can be times with no wind. Thus, a water tank or storage facility should be installed together with a wind-powered water pumping system to ensure continuous water supply [13]. Unsteadiness of wind current is a problem that limits wind

turbine utilization. To mitigate such limits and utilize renewable resources more efficiently, lab-scale models of water pumping systems that use wind power in combination with solar power have been developed. These systems received the highest electricity from their solar panels during February through June, which was found on average to be within a range of 400-480 W per month. Alternately, electricity from their wind turbines is highest from September to December, with an average electrical power about 0.8 – 1.0 W per month. Most of the derived electricity is stored in batteries to operate the water pumps. Although electricity from a wind turbine is considered low, the hybrid system allows solar power and wind power to be utilized efficiently [14]. When a hybrid system equipped with a 1.08 kW solar panel and a 1kW wind turbine was installed in an area for real use, it was found that the proportion of electricity from the solar panel and the wind turbine was 85.80:14.20%. The system was capable of pumping water for 18,396 m³ per year (1,533 m³ per month). The operational cost of the system was 897,186.62 baht. Therefore, the maximum cost of water pumping for this system was 3.25 baht/m³. In comparison, a diesel oil-powered water pumping system had a cost of 0.99 baht/ m³, and a gasoline-powered system had a cost of 0.72 baht/ m³ [15]. That means the renewable energy-based system is more expensive. Therefore, it is very important to study the appropriateness of each area by considering light intensity and wind speed before installing a solar-powered/wind-powered water pumping system.

Currently, geographic information system (GIS) have played an important role in assessing spatial mapping analysis potential of an area. GIS is a system that can record data to represent real areas in terms of maps. GIS stores various types of data as layers, which can be overlaid and presented together. Therefore, GIS is a technology that can be used to assess the potential of renewable energy in an area for water pumping systems. When using GIS to analyze Thailand's area as a whole, areas appropriate for solar cell installation accounted for 43% of the country's total area. The regions that were most appropriate for solar cell installation are the Central, Northeastern, Eastern, and the Southern regions, respectively. From the analysis results, yearly production capacity of different types of solar cells could be calculated to find the type that is most efficient and suitable for areas in Thailand [16]. Potential and worthiness of installing renewable energy-based systems in various areas can also be assessed. Wind energy is another type of renewable energy that is installed in Thailand. Application of GIS can reveal areas that are suitable for installing wind turbines in Thailand based on their potential and electricity demand. A study found that Yala province was highly suitable for installing wind turbines for electricity generation. The wind turbines installed in the province could generate electricity up to 979,018 MWh per year. This system can reduce greenhouse gas emission at 412,971 tons CO₂e per year, and has an energy cost of 3.45 baht per unit [17]. Cambodia, a neighbor of Thailand, also assessed its area's potential for wind-based electricity generation with GIS before deciding to invest in wind turbine installation. The assessment found that Kampot province in Cambodia has a high potential for installing a large wind-turbine electricity generation system worthy of investment [18]. Spatial analysis with GIS can be applied in various aspects. In India, the spatial mapping of availability and demand of energy resources was greatly helpful in the integrating regional energy planning through an appropriate energy supply–demand matching. India also used the GIS Taluk Wise mapping model for renewable energy potential assessment. The result showed that India has higher global solar radiation and wind energy during summer, monsoon and winter seasons. Hence, India appears to be the country with the highest number of small hydropower plants with a capacity of 36 MW [19]. Oman used GIS-based solar radiation maps and found that all of its land has a very high potential for year-round solar-based electricity generation [20]. Indonesia used an artificial neural network and GIS for mapping its solar energy potential. The solar irradiation maps could provide useful information about the profile of solar energy resource as the input for solar energy system implementation [21].

Therefore, in order to have efficient water systems for agricultural activities in remote areas and allow them to reduce production cost by relying on themselves, communities should have an appropriate renewable energy-based water pumping system. Thus, application of GIS is necessary for spatially analyzing the potential of water sources and renewable energy sources required for the optimized water pumping system. Such analysis can ensure security in renewable energy utilization and water

source management for agricultural activities of local communities. Therefore, this research was conducted with two objectives: (1) to analyze the potential of communities' water sources, and (2) to analyze for an optimum renewable energy-based agricultural water system for small-scale farming of the community.

2. Methodology

2.1 Area

This research was conducted at the Smart Community of the Asian Development College for Community and Technology (adiCET) in Chiang Mai Rajabhat University (19°01'25.1"N 98°56'23.7"E) as a model of a remote area. The spatial mapping for a renewable energy agricultural water system was analyzed at the small community farm and covers about one rai inside the Smart Community. The Smart Community combines residential, office and business areas together. The community business area comprises a convenience store, restaurant, and coffee shop and therefore represents a small model community.

2.2 Primary data

Data is crucial when analyzing the potential of community water sources and analyzing for an optimum renewable energy-based agricultural water system for small-scale farming in the community. The primary data was collected via GPS survey. The GIS data was analyzed by using Spatial Analysis Extension to determine the spatial mapping analysis for potential water sources in the community area based on the distance to a suitable agriculture water system. The physical water sources are an irrigation canal, reservoir and a water tower. The suitability distance levels from farm to water source are shown in Table 1. The suitability distance level is considered high if the distance between the water source and the agriculture area is less than 100 meters. For distances between 100 to 200 meters, the suitability level is considered as medium. If the distance is more than 200 meters, the distance suitability level is low.

Table 1 Suitability levels of distance from water source to farm according to the Royal Irrigation Department [1]

Distance (meter)	Suitability Level
< 100	high
100 – 200	medium
> 200	low

2.3 Secondary data

The secondary data include the quantity of groundwater, which was obtained from the Royal Irrigation Department [22]. The data for light intensity and wind speed during 2006 – 2013 was obtained from the Ministry of Energy [25] and the Thai Meteorological Department [23], respectively. The renewable energy source data was used to determine the suitable renewable energy-based agricultural water system. Potentials of light intensity and wind speed are shown in Tables 2 and 3, respectively. The light potential is divided into 2 levels low and high. The criteria are determined based on the power required for the appropriate water pump size. The high light potential level is based on agricultural water pump size for a medium depth well. For Thai farmers, a 3 horsepower pump is sufficient for water pumping which requires approximately 54 kW/day at maximum pumping duration. Therefore, the light intensity should be greater than 15 MJ/m² – day to achieve the appropriate power. For the wind potentials, the criteria are divided into 3 levels low, medium and high based on wind speed. For commercially available wind turbines, wind speed needs to be above 13 km/h. Therefore, this value was set as the low wind potential level. The rate of water pumped is determined from the wind speed and turbine speed. Wind speeds in the range of 13-17 km/h will provide approximately similar water pumping rates, therefore this is the medium wind potential level.

For wind speeds higher than 17 km/h, the pumping rate would be double that of the medium level. Therefore, 17 km/h was set as the high wind potential level.

The data collection process is shown in Figure 1, the data was analyzed by using Spatial Analysis Extension from the GIS to determine the spatial mapping for the suitability of water sources and a suitable renewable energy. The mappings for both sets of data were overlaid to determine the suitable renewable energy water system for the small community farm. The renewable energy pumping system was tested in the study area of one rai.

Table 2 Potential of light intensity from the Ministry of Energy [25]

light intensity (MJ/m ² - day)	Potential of light intensity
> 15	high
< 15	low

Table 3 Potential of wind speed at 10 meter from The Ministry of Energy [23]

wind speed (km/h)	Potential of wind speed
> 17	high
13 - 17	medium
< 13	low

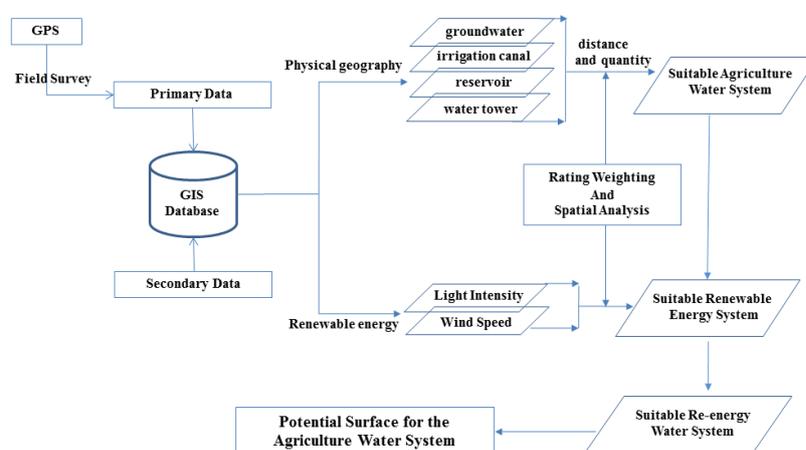


Figure 1 Framework to analyze potentials for renewable energy-based water pumping systems

3. Results and discussion

3.1 Spatial analysis of community water sources.

The study area has a seasonal water demand of 4,000 L/rai/day for agricultural farms, however the area has a seasonal water availability of 1,154 mL/year which is not enough for farming [26].

The main sources of water consist of a reservoir, an irrigation canal, and 2 water towers (Figure 2). The spatial mapping analysis by GIS results revealed that the distances between the water sources and the organic farms ranged from 200 - 520 meters. Figure 3 shows that the reservoir is the furthest distance, 520 meters from the farming area. The irrigation canal distance is 200 meters and the water towers' 1 and 2 have distances of 520 and 200 meters respectively.

Therefore, water tower 1 and the reservoir are unsuitable water sources as they are too far from the farm. Water tower 2 and the irrigation canal are better but they are also unsuitable. The water's main purpose is for use in organic farming. However, the reservoir and both water towers are unsuitable sources because they all contain chlorine [27]. Although the irrigation canal was developed with its main purpose begin agriculture use, its water contains chemical contaminants and is not suitable for organic farming as well. So, another alternative water source must be located.

3.2 Groundwater

According to the spatial mapping analysis on the suitable distance for a water source, it was found that the most suitable water source for organic agriculture in the community should be groundwater instead of the surface water. Therefore, the next step was to analyze the quality and quantity of groundwater to be used as an alternative water source for the community. The results revealed that the study area's geologic strata consisted of pebbles, sand, silt, and clay. The depths of the groundwater ranged from 20 to 250 meters. The quantity of groundwater that can be acquired was over 20 m³/hr [28] which was enough for agricultural farming in the area. Therefore, the results indicated that the Smart Community area has a high potential for groundwater, which is sufficient for agricultural use in the community (Figure 3).

An advantage of groundwater is its steady availability. Groundwater can be pumped and stored at any time without having to wait for water released from another source. This reliable water source can help make sure that the agricultural production of the farmers will not be affected by water shortage. The analysis in this study found that the groundwater studied has sufficient quantity and suitable quality for the community's agricultural use. This can be done by drilling a well and using a pump, which is generally powered by either diesel or electricity. This research aims to apply the spatial mapping analysis to the remote areas without electricity. The cost difference between renewable and diesel pumping system were compared. Therefore, reducing agricultural production costs and ensuring security in energy and water sources, as well as to enabling community self-reliance. The water pumping system should utilize a renewable energy source that is suitable for the area. Hence, the analysis for an appropriate renewable energy source was conducted. GIS was applied for this purpose so that the analysis results can be implemented with a real pumping system afterwards.



Figure 2 The distances between the water sources and the community farms

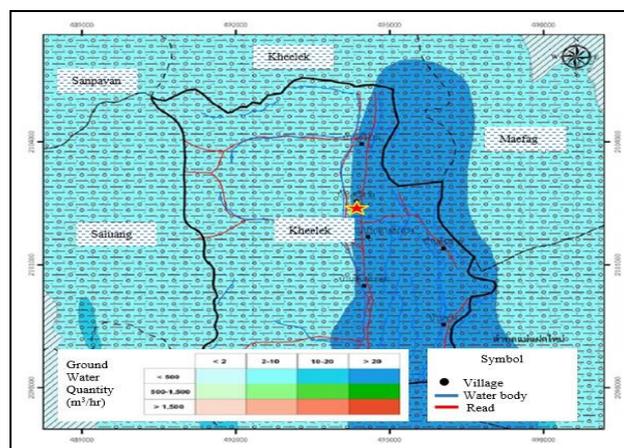


Figure 3 Ground water quantity (m³/hr) of the Smart Community in Mae Rim District, Chiang Mai Province

3.3 Potential of light intensity (Solar Energy)

Solar energy potential of the study area was assessed by applying GIS analysis with the secondary data of light intensity. The results revealed that, during summer (from March to June) and the Rainy season (from July to October), the potential values of light energy in the area were between 15 - 22 MJ/m² - day and 15 - 20 MJ/m² - day, respectively. These values are considered to be of a high level. For the winter season, the area's light energy potential values were 13 - 21 MJ/m² - day, which a range from a low level to a high level (Figure 4). The analysis results lead to a conclusion that the average solar energy potential of the area was between a low and high level. The solar energy value in general ranges between 15 - 22 MJ/m² - day, with a mean value of 18 MJ/m² - day, signifying that the area has a high level of solar energy potential (Figure 5). That means electricity derived from the solar cells installed in this area is also at a high level [29]. The result from this solar energy potential analysis corresponds to the study of the Ministry of Energy [28], which found the average solar energy in Thailand to be at 18 MJ/m² - day with the maximum of 22 - 24 MJ/m² - day in the Central and the Northeastern regions [4].

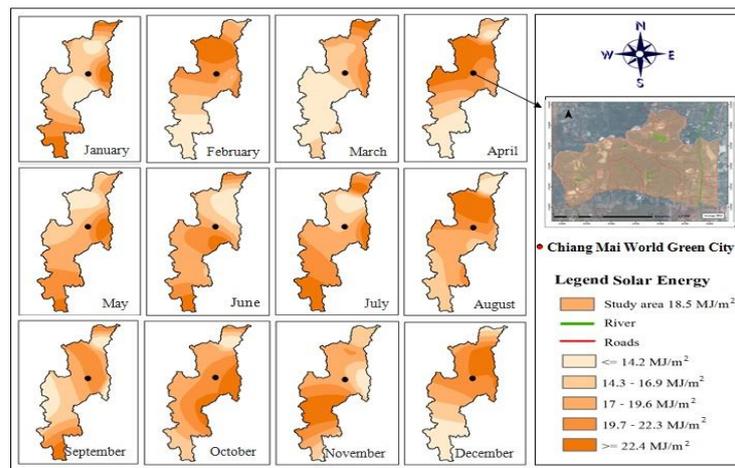


Figure 4 Monthly solar energy in 2014 in the area of Chiang Mai Province, Thailand

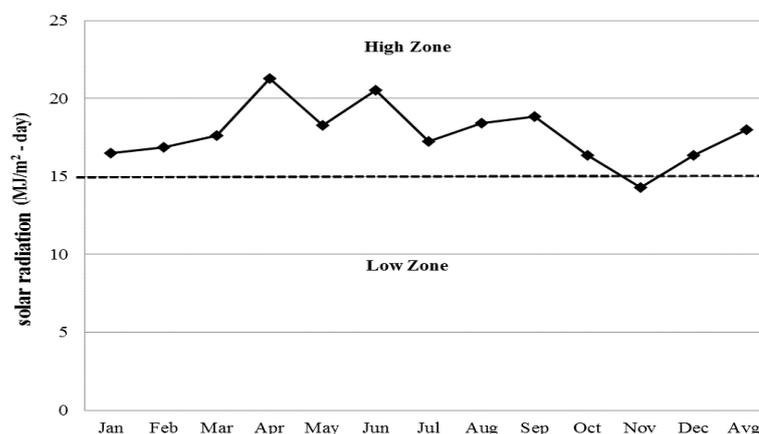


Figure 5 Monthly solar radiation in 2014 in Mae Rim district, Chiang Mai Province, Thailand

Since air temperature can also affect the performance of solar cells, historical temperature data from 2006 to 2013 was also applied to this analysis study. The data was analyzed to find the trend in temperature change. It was found that air temperature in the area tends to increase over time. This trend has to be taken into consideration when making decisions established on solar energy-based electricity generation system investment. In principle, electricity voltage will drop by 0.5% when the air temperature rises every 1 degree Celsius. This phenomenon also affects the maximum

capacity of solar cells, which will decrease with an increase of temperature [29]. A point of concern is to select efficient solar panels that are suitable for the water pumping systems [15] because each type of solar cell is suitable for a specific application. Regarding DC power supply from solar panels, a study showed that panels made of Amorphous Silicon solar cells are the most appropriate for general use [32]. However, in the case of this solar energy-based water pumping system, Mono-crystalline Flexible Solar Panel type solar cells were found to be more efficient (highest pumping rate) and provided the highest economic break-even point (Payback period and Internal Rate of Return) compared to Poly crystalline and Amorphous Silicon solar cells [17]. Therefore, to utilize solar energy for running a pumping system in the community, the type and technology of the solar cell must be taken into consideration. The technology should be able to help reduce the temperature of the solar cell so that the solar-powered water pumping system can function at its highest efficiency (Figure 6).

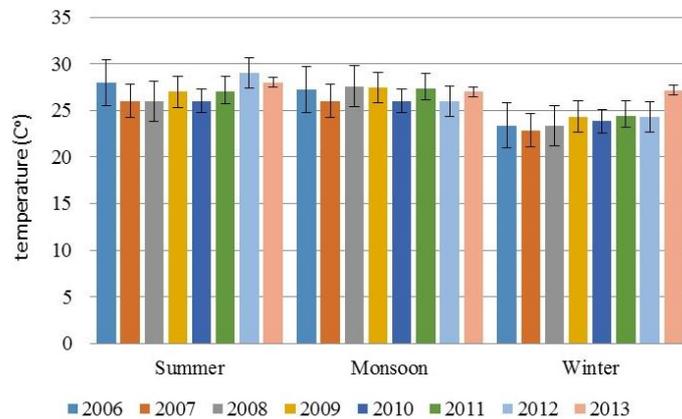


Figure 6 Trend of temperature by season from 2006 – 2013 in Chiang Mai Province, Thailand

3.4 Potential of wind speed (Wind Energy)

The analysis on potential of wind power revealed that the area had a low level of wind energy potential all year long. Wind energy at a level 50 meters above the ground was found to be between 0.8-1.4 m/s, with an average of 1.20 m/s. For detailed information, wind energy potential was analyzed for all the 3 seasons namely summer (from March to June), rainy (July to October) and winter (November to February). It was found that wind energy in the summer and rainy seasons ranges between 1.1-1.4 m/s, and drops to 0.8-1.1 m/s in winter (Figure 7-8). This result is in agreement with the research of the Energy Policy and Planning Office (EPPO), which also found the wind energy potential in Thailand is low. Only coastal areas in Thailand were found to have a sufficient wind energy potential [29].

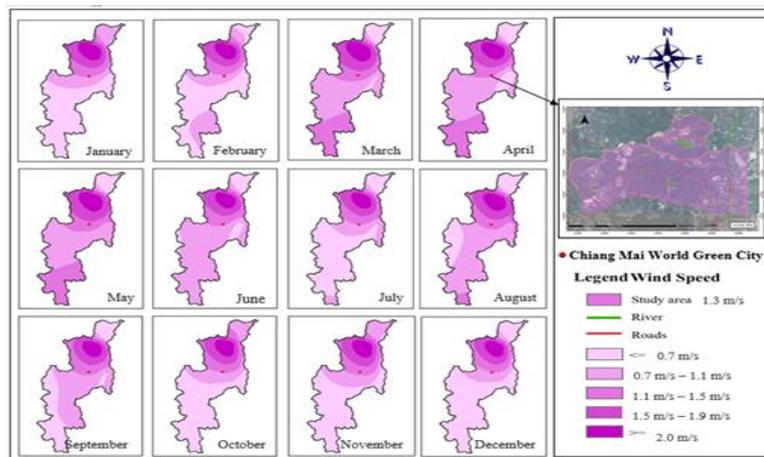


Figure 7 Monthly wind energy in 2014 in Chiang Mai Province, Thailand

Based on the retrospective analysis of wind speed data, it was found that wind speed in the summer kept decreasing apparently over time. The curves show a slight decrease of wind energy during the rainy and winter seasons (Figure 9). According to the data, the potential of wind energy in the area should also keep decreasing. In addition, only 0.2% of Thailand’s land has a high potential for use as wind energy. Wind energy also has limitations regarding the unsteadiness of wind current. Wind turbines are therefore limited to being installed only along the coastline or on top of wide open mountainous areas [30]. Moreover, the installation cost of wind energy-based electricity generation systems appears to be significantly higher, while having lower efficiency, when compared to those of solar energy systems for the application on water pumping [15].

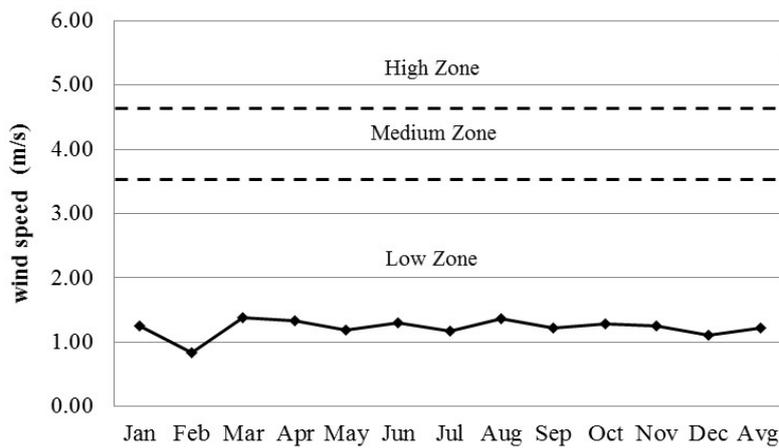


Figure 8 Monthly wind speed in 2014 in Mae Rim district, Chiang Mai province, Thailand

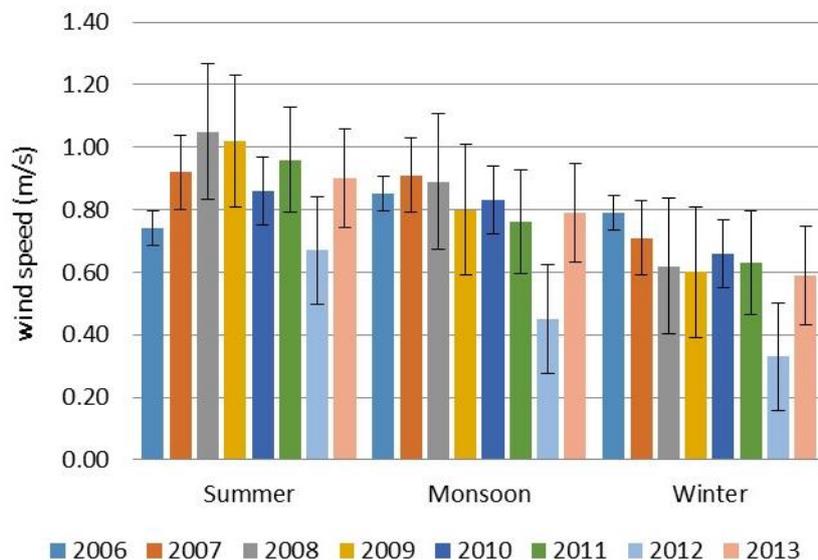


Figure 9 The trend of wind speed change by season in Chiang Mai Province from 2006 to 2013

According to the analysis on wind and solar sources in the area, a conclusion was made that solar energy is the most appropriate source to be used with the community’s water pumping system. Compared to a wind energy-based system, a solar-powered water pumping system has lower installation costs, and can work 6 times more efficiently [6].

3.5 The Small-Scale Community Farm Model

The spatial mapping analysis by GIS was applied with relevant and overlay data to determine suitable water sources and suitable renewable energy for water pumping. The result shows that groundwater instead of surface water sources is the most suitable for organic agriculture and solar energy was found to have a higher potential for powering a water pumping system in this area. The water demand of the community farm was 4,000 L/day/rai based on the calculation of vegetable production. Based on the water demand, the PV pumping system with a DC pump will cost 11,800 baht in the first year and no cost in the second year (Table 4). Comparing to diesel pumping, the system will cost about 73,325 baht/year which is about 6 times higher than the PV a pumping system. The PV pumping system has a stable pumping capacity from the available solar irradiation throughout the year.

Table 4 Cost of the solar energy pumping system and the diesel pumping

Pump system	Cost (baht)		Total (baht)
	System	Fuel yearly	
<u>PV pump system</u>			
- DC pump 12 VDC, 3.0 A (STC-4000 L) at Pumping rate 4,000 L/day	4,300	-	11,800
- Mono-crystalline PV panel 40W, 18V (3 panel) at 2,500 baht/panel	7,500		
<u>Diesel pump system</u>			
- Pumping rate 4,000 L/day - 3,600 rpm - Diesel cost 25.99 baht/L (based on 8 June 2015)	32,500	40,825	73,325

Assumption: water demand at 1,320 m³/year; 1.19 L of diesel/m³ of water

For the installation of a solar-powered water pumping system, the water well drilling location needs to be planned and this step is highly important. All analysis results needed to be overlaid with each other to find the optimum spot for installing the system in the area. Most parts of the Smart Community were hilly and covered with large trees. The surrounding areas consist mainly of houses and shops. There is only the area in the northeastern part of the agricultural area that is flat and wide open. However, that area also has many houses and people. Thus, the water well for the solar-powered water pumping systems needed to be drilled in area next to the residential area in the eastern side. The water tank was built down to the south in an area higher than the farms so that the stored water can be used for agricultural activities efficiently (Figure 10). The model farm provides vegetables for 20 members in the Smart Community. Additionally, approximately 50 visitors per month attend training and tour the Smart Community to learn about the integration of renewable energy and agriculture. The vegetables are for consumption and selling at the green market in the local community.



Figure 10 Installation of the renewable energy-based water pumping system for agricultural use of community people in the study area

Spatial mapping analysis with GIS is an effective method for determining the potential of water resources and renewable energy for a small model farm in the Smart Community of adiCET. This method is more accurate than the area assessment using just Thailand's solar or wind maps [31]. The country maps are in large scale and not detailed to the community level and they're also outdated. In this work, spatial mapping analysis with GIS combined with accumulated yearly data from Meteorological Stations and the Royal Irrigation Department has proven to be the appropriate technique for identifying site location, water demand, renewable energy resources, limitations, technology and the scope of the water pumping system for the small farm area in the community. The renewable energy water system will provide sufficient and sustainable water for the farmers throughout the year.

4. Conclusion

This research aimed to use spatial mapping for analyzing the community's agriculture water sources as well as renewable energy sources for a water pumping system in the Smart Community of the Asian Development College for Community Economy and Technology, Chiang Mai Rajabhat University.

With the use of spatial analysis capability of Geographic Information System (GIS), the results showed that surface water source were located at approximately 100-200 meters away from the community. And the suitability of this water source is at a moderate level. The results also indicated that the Smart Community area has the potential for groundwater usage at 20 m³/hr, which is sufficient for the agriculture in the community. PV-DC pumping systems were designed and installed. Economic analysis for PV-DC and Diesel pumping systems were compared and the PV-DC pumping system's cost of operation was about 6 times lower than the Diesel pumping system. The savings was from the elimination of fuel. The format of community agriculture in a remote area needs to be planned by determining the appropriate water source and the sustainable and economical technology for water pumping.

The current information on water and energy resources is available through the Royal Irrigation Department and Meteorological Stations. Data integrated with spatial mapping analysis with GIS is the appropriate platform to analyze water demand and resources along with site specific renewable energy potentials for small farms in the community. The information will assist in renewable energy water pumping designs. These criteria and information are a very important starting point allowing farmers to create sustainable energy and low carbon agriculture.

Acknowledgements

The author would like to acknowledge Uttaradit Rajabhat University for the Ph.D academic scholarship and the Asian Development College for Community Economy and Technology, Chiang Mai Rajabhat University for the research facilities.

References

- [1] Department of Water Resources; (2012); The project of study to the agriculture ground-water system; Development of water resources office; Bangkok; Thailand.
- [2] OK Nation Blog; (2000); Renewable energy and the environment; Division of Science and Technology; www.oknation.net/articles; Accessed 2 June 2015.
- [3] PTT Public Company Limited; (2015); Diesel price; Bangkok; Thailand.
- [4] Somchai S; (1995); Techno-Economic Analysis of Direct - Coupling Photovoltaic Water Pumping Systems for Irrigation; Master's thesis; King Mongkut's University of Technology Thonburi.
- [5] Energy Policy and Planning Office; (2000); Electricity production by solar cells. Ministry of Energy; Royal Thai Government; Bangkok; Thailand.
- [6] Sirikunya S; (2011); The Solar water pumping project to promote the use of the community electrical systems in areas difficult to reach; Report of innovation by research; Kasetsart University. Bangkok, Thailand.
- [7] Thansarnok H; (2013); The feasibility study for a solar pumping System Agricultural Sufficiency Economy; Project; Faculty of Science and Technology; Thammasat University.
- [8] Suthat P; (2014); Solar Inverter Pump: The innovation and engineering; National Electronics and Computer Technology Center (NECTEC); Bangkok; Thailand.
- [9] Sungsang L; (2010); Study of a Solar Water Pumping with Bubble Pump Technique; (Master's thesis); King Mongkut's University of Technology; Thonburi.
- [10] Silapachai P, Wirachai R; (2012); Efficiency Analysis of 1 kW Wind Machine for Water Pumping. Abstract; The 8th Conference on Energy Technology Network of Thailand; E-NETT; Mahasarakham; Thailand.
- [11] Department of Energy Development and Promotion; (2010); Hummer Wind Generator : Wind Pump; Ministry of Science Technology and Environment; Bangkok; Thailand.
- [12] Phetcharin R; (2014); Study and Development of windmills for pumping water use in agriculture; Khon Kaen Province; Research and Development; Khon Kaen University; Khon Kaen, Thailand.
- [13] Pitchit P; (2010); Windmills pumped water self-sufficient; A report on the research; Artifacts energy; Banphaeo Industrial and Community Education Collage; Samut -Sakhon, Thailand.
- [14] Chainusorn K; (2009); The Simulation of a Hybrid Solar-Wind Water Pumping System Using TRNSYS 16.01; The 19th Thaksin University Annual Conference; Songkhla; Thailand.
- [15] Jompoop W; (2008); The Development of a Hybrid Solar and Wind Water Pumping System for Rice Farming in Phattalung Province; A report on the research; Bangkok; Thailand.
- [16] Samart W, Patamaporn S; (2012); Analysis of Site Suitability for Photovoltaic Installed in Thailand Using GIS based and Solar Radiation Map; Master's thesis; Department of Electrical Engineering, Faculty of Engineering; Kasetsart University; Bangkok; Thailand.
- [17] Yutapong S; (2012); Evaluation of electricity generation potential from wind energy of thailand by using gis and carbon stock change of land use method TSME; The 3th International Conference on Mechanical Engineering; Bangkok; Thailand.
- [18] Taweasuk T; (2008); An Investigation of Wind Energy Potential at Kampot in Cambodia; The 3th Graduate study Conference; Silpakorn University; Bangkok; Thailand.
- [19] Ramachandra T V, Shruthi B V; (2005); Spatial mapping of renewable energy potential; Renewable and Sustainable Review; vol11:1460 – 1480.
- [20] Adel G, Yassine C;(2010); Solar electricity prospect in Oman using GIS-based solar radiation

- map; *Renewable and Sustainable Review*; vol 14: 790 – 797.
- [21] Meita R et al; (2011); Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system; *Renewable and Sustainable Review*; vol16 : 1437 – 1449.
- [22] The Control Groundwater Station; (2013); Quality of Groundwater; www.gcl.dgr.go.th; Accessed 2013.
- [23] The Monitoring Stations Chiang Mai International Airport; (2012); Data of wind speed during 2006 – 2013; <http://www.cmmet.tmd.go.th>, Accessed 2012.
- [24] The Royal Irrigation Department; (2012); Suitable Level of Distance between water source and agriculture area; Bangkok; Thailand.
- [25] The Ministry of Energy; (2009); Potential of light intensity and wind speed at 50 meter; Bangkok; Thailand.
- [26] Northern Meteorological Center; (2015); Average Rain Data of Amphoe Maerim; Chiang Mai; Thailand.
- [27] Department of Agriculture; (2012); Suitable Water for Agriculture; Bangkok; Thailand.
- [28] The Groundwater Resources office; (2013); The potential for groundwater in Chiang Mai, Thailand; Department of Groundwater Resources; Bangkok; Thailand.
- [29] Renewable Energy; (2012); Solar Cell; Electricity Generating Authority of Thailand; Bangkok; Thailand.
- [30] Energy Policy and Planning Office; (2009); Wind Energy; Study on the promotion of electricity from renewables; Thammasat University Research and Consultancy Institute; Bangkok, Thailand.
- [31] Ministry of Energy; (2010); Thailand Solar Energy Overview; Department of Alternative Energy Development and Efficiency (DEDE); Bangkok; Thailand.