Evaluation of Solar Energy Potential for Electricity Generation Using Geographic Information System

N. Phuangpornpitak

Abstract— *Installations of photovoltaic (PV) systems have shown growth rates around the world. Nevertheless, there are concerns about the site determination of PV systems among the implementers and project designers as the success of a project greatly depend on the proper selection of its site. A PV system design should consider the parameters of energy resources, load demand and population density of the site. To address this issue, a Geographic Information System (GIS) based method has been developed to select technically and financially feasible sites of a given region. A GIS database with data on solar radiation and topography has been developed, and used for assessing the technical potential of the solar PV resource. It also considers the electricity demand, land use, local potential and constraints such as electricity network coverage, river, road etc. and thus identifies suitable areas for installing PV systems. The financial analysis based on the payback period identifies the financial viability of the investment. The methodology has been applied to Sakonnakhon province which located in the northeastern region of Thailand. It is expected that the output of this GIS model would help the project designers to select suitable sites for a PV system. In addition, policy makers and planners could use this method as a decision support system for estimating the load demand, technical and financial viability of these through easy visualization and could analyse either an installed project or a new project to be considered for implementation. This paper describes the development of the method and details the output. In addition, it also shows the application of the method, clearly showing the applicability of the developed method using a suitable tool for assessing PV system.*

Keywords— **Geographic Information System, PV system, Renewable energy, Sustainable.**

1. INTRODUCTION

As climate change is the greatest environmental challenge facing the world today, it is therefore essential to bridge energy gaps that create supply and environmental insecurities [1]. A steady and secured supply of sustainable energy can be achieved through energy diversification, greater focus on promotion of cleaner, more efficient and less-polluting technologies, along with greater use of indigenous forms of renewable energy (RE) [2]. After oil crises of the 1970s, utilization of renewable energy worldwide has increased considerably. Of the available renewable energy technologies, photovoltaic (PV) is found to be promoted and the use of solar energy for electricity generation is being significantly considered for satisfying part of the energy demand in the world.

In Thailand, the annual average intensity of daily total solar radiation is 17 MJ/m^{2}day (or 4.72 kWh/m^{2}day) which can be considered as fairy good [3]. Most residential homes are connected to the electric grid. Nevertheless, there still exists many rural areas have not been supplied electricity because of huge investments in transmission and distribution [4]. The grid connection has been considered as the preferable option to electrify rural communes [5]. However, cost of electricity supply for these areas is higher than those for urban ones due to the less dense populated areas that would also lead to much transmission and distribution losses and its characteristic of local load profile [6,7]. These are considerable problems of electricity supply. To solve the problems of supplying electricity to rural areas, one option is the development of distributed power generation.

Distributed generation represents an opportunity to quickly electrify for rural areas that offers several advantages when compared to centralized conventional models for power generation [8]. With emerging technological development in renewable energy technologies, electricity generation from solar energy is increasingly focused by electricity planners and policy makers as well as electricity consumers due to its significant benefits [9]. Solar electricity generation can be defined as supply option to meet energy needs from customers served by direct connecting to an electric distribution system.

Although the distributed generation of solar energy resource is high potential for supplying electricity in Thailand, only a small portion of it has been exploited so far [3]. It is the government policy to develop the solar electricity generation by encouraging private investor or local committee to invest in Thailand. Furthermore, grid connection is the main option of rural electrification in Thailand that was carried out by the Provincial Electricity Authority (PEA) in recently year. In order to make a distribution in the assistance for decision maker this study attempts to identify and analyze the suitable areas for solar electricity generation in Sakonnakhon province which located in the northeastern region of

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Thailand. This can be illustrated by developing a methodology using Geographic Information System (GIS).

2. METHODOLOGY

The method evaluates electricity demand, technical and financial potential of solar energy resources of a location and identifies the potential sites for installing PV system. ArcView, GIS software under Windows was used for the GIS works. This model is intended to be used by those who wish to identify the suitable location to install PV system. This section describes the procedure on how to use this model for any given location. First, it lists the data required for the location and secondly, it describes the steps of developing a similar model appropriate to that location.

2.1 Data required for the method

A large number of map and data are required for electrification project. Starting from the selection of the village and evaluate the energy demand at any site, a large number of topographical, administration data and maps have to repaired, analyzed. GIS could be a useful tool for handing such a large quantity of data and maps for arriving a decision regarding formulation of the electrification project. The following types of data are required to develop the model:

- Average electricity consumption of the region under consideration.
- Topographical data (population of region, number of households, solar radiation, and wind speed).
- Spatial data (administrative area map, road network map, river network map, land use pattern map, existing and electricity grid network map).
- Non-spatial data (discount rate, equipment cost, O&M cost, system life, fuel cost, and probable revenue)

2.2 Assumptions used

The technical potential resource is defined by the energy that can be produced using existing technology and is limited by commercially available photovoltaic module [9].

To find the technical potential of solar PV system, it is assumed that all available areas in the region would be fully covered by solar with selected PV module. However, for practical purposes the PV module cannot be installed on the agricultural land, forest, road and river. Therefore, the available area is determined by deducting the areas required for these infrastructures from the total area of the sites. The available area/region is restricted of at least the followings:

- Road and river area including a buffer area (500m buffer): To exclude the areas near road and river for safety from flood and other natural calamity,
- Forest and agricultural land : As solar panel cannot be installed in these areas,
- At least 2 km from the electricity grid line: So that the extension of electricity may not be feasible,
- Installation area for PV panel can be 70% of the available area: Even in the available areas not all areas are suitable for installation of panel due to the shadow of tree, roof of the house etc.

The annual average of daily sum solar radiation data was used to calculate the solar potential. By covering the available area with a specific solar module the total energy resource potential for solar photovoltaic are estimated.

The energy demand of the suitable locations where there is good solar resource potential was used to design the PV system. After determining the size of the system the net investment cost, net operation cost, revenues and overall cash flow was estimated. Life cycle cost of the systems was calculated. The unit cost of electricity was calculated from the total annual cost including annual discount and O&M cost and total energy generated from the system.

2.3 GIS implementation

As the proposed model and the results are based on GIS, it is easy for the planners and project developers to visualize the results. The output of the proposed model would help the project designers to select suitable sites for solar PV system. In addition, policy makers and planners could use this method as a decision support system for estimating the load demand, technical and financial viability of these through easy visualization and could analyse either an installed project or a new project to be considered for implementation. In addition, it also shows the application of the method, clearly showing the applicability of the developed method using a suitable tool for assessing solar PV system.

(a) Estimation of electricity demand

Electricity demand model helps to calculate the demand of electricity of a location or area. The amount of electricity consumed by the following sectors is required to get a clear view of the total electricity demand of a location: household, agriculture, industry, public lighting, school and health center. From the electricity consumption data, annual electricity demand is estimated using equation (1):

$$E_T = \{(E_H \times N_H) + E_I\} \times N \tag{1}$$

where, E_T is the total electricity demand (MWh/yr)

E_H is the average electricity consumption per household (kWh)

E_I is the average electricity consumption for school, college, health centre etc. (kWh)

N_H is the number of households

N is the number of days in a year

An administrative map showing the administrative boundary of the region is used as a platform of the GIS tools. This is the first layer of the GIS model. The second layer is the population density map. Population density data was added with the administrative area map and using ArcView the population density map was created.

The electricity demand estimated was converted into dBASE IV (DBF IV) file. The electricity demand map was created from the results. This map is layer 3, which shows the electricity needs of the areas.

(b) Technical potential of solar photovoltaic

The spatial variability of energy demand and matching of solar radiation as well as energy demand on a geographical basis makes the model interesting and useful [11-14]. The available area was estimated using ArcView software to find the technical resource potential of the location. Using equation (2) the available installation area for calculating the electricity production from PV was derived [15]:

$$A_V = \left[\{(A_T)\} - \{(A_{RBf}) + (A_{RiBf}) + (A_F) + (A_A)\}\right] \quad (2)$$

where, A_V is an available area for installing PV panel (m^2)

A_T is the total area of the location (m^2)

A_{RBf} is the buffer of road areas (m^2)

A_{RiBf} is the buffer of river areas (m^2)

A_F is the area of forest (m^2)

A_A is the area of agricultural land (m^2)

Administrative boundary map, road network map, river network, land use and vegetation map were used as input data. Road and river buffers were created and joined together using geo-process wizards to get one map. This map was then clipped from the administrative area map. The result gives the non-buffer area. Using the available area technical potential resource of solar was estimated. The results showed by map. A map was produced from these results showing the resource potential density of solar technology.

After estimating the solar energy resource potential, the results were transferred to DBF IV for use in ArcView. The solar resource potential density map were created and presented as less, adequate, good, very good and excellent. The mean value of the solar resource potential density was chosen as good. Below the mean values were equally divided into two categories and termed as adequate and less and above the mean value were also divided into two categories and termed as very good and excellent.

For a PV system, those areas are suitable where there is very good solar potential. Raster[1] based analysis is done using ArcView to get the final map which shows the areas with good solar resource potential. To do that, first the map was transformed into grid map showing the energy resource potential of PV.

The grid maps were then reclassified and ranked. The most suitable areas were ranked as 5 and non-suitable areas were ranked as 1. A final map was created showing the suitable areas according to solar potential classification. Most preferred area should have less payback period

3. APPLICATION OF THE MODEL

The model aims to assist in the identification of potential areas for decentralized rural electrification using GIS tools. It evaluates electricity demand, the technical and financial potential of solar energy resources of a location and identifies the suitable sites for installing PV system. The method was applied to Sakonnakhon province. The reasons for selecting this area for applying the model are as follows:

- There is ample sunshine in this region, and
- Availability of data (i.e. the digital map, the meteorological data and the electricity usage of study area)

The data used in the present case study are:

- Digital map of administrative boundary
- Digital map of road and river
- Data of electricity consumption and population
- Technical characteristics of solar module

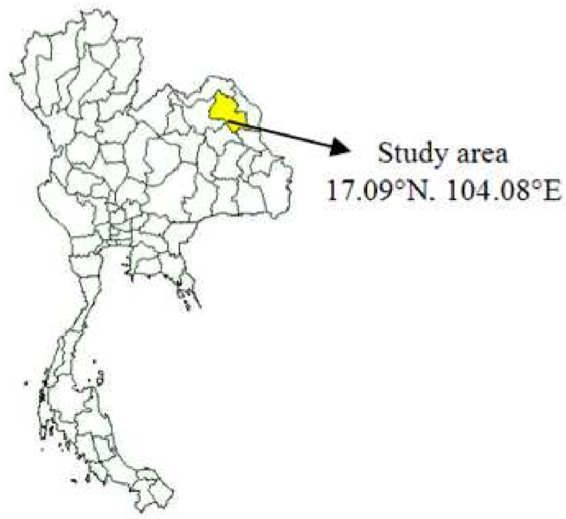

Fig. 1. Location of the study area.

Fig.1 shows the location of the study area. Sakonnakhon province located in the Northeast of Thailand which the total area of 9,605.8 km^2. The latitude of the area is 17.09°N and longitude is 104.08°E. The average temperature of the area ranges from 14-34°C. The annual average daily solar radiation is about 5.3 kWh/m^2-day corresponding to 19 MJ/m^2-day. The study area receives an average of 6.5 sunshine-hours per day.

[1] Raster data is characterized by pixel values. Raster GIS information is represented as a grid of cells. Every cell on the data surface has a value for an attribute, even if it is zero. Raster analysis is more accurate.

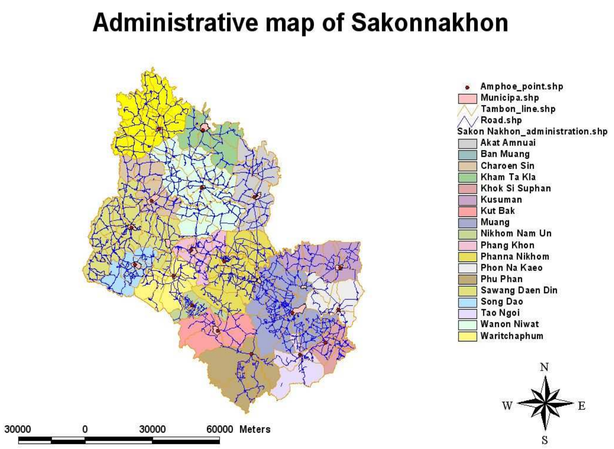

Fig. 2. Topographic map of Sakonnakhon province, Thailand.

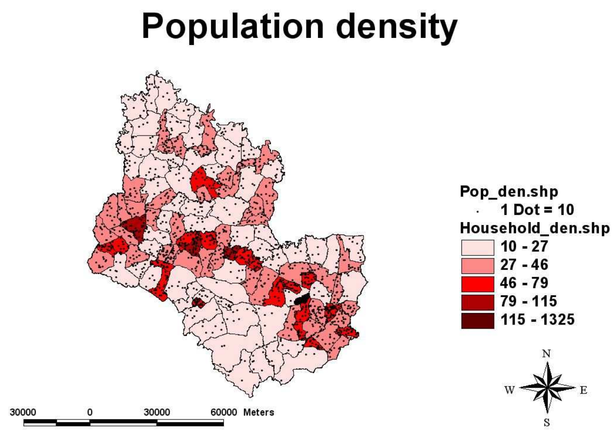

Fig. 3. Population density of the study area.

Fig. 2 shows the topographic map of Sakonnakhon province. The map shows the administrative boundary, river network, road network and settlement of the study area. There are 18 districts in Sakonnakhon province. Fig. 3 shows the population density of the study area. At present, the total population of Sakonnakhon province is 1,113,064[2]. The model has been applied only 12 districts from the total of 18 districts in the province.

3.1 Electricity status and solar PV used in the study area

The main sources of electricity in the study area are utility grids via medium-voltage transmission lines except some areas such as remote temples and mountainous areas which far from the grid. These areas use kerosene lamps, lead-acid battery systems or diesel generators serving electricity to the localities.

The use of solar PV for electricity generation in Sakonnakhon province has been started since 2001 which the first PV system installed at Phupan royal development study center for demonstration purposes with the PV capacity of 2.1 kW_p. However, the system is currently unused since the failure of inverter.

Recently, solar home systems and PV water pumping are the applications of solar energy uses in Sakonnakhon province. In addition, the battery charging stations have also been used in the remote temples.

The prospect of PV system installation could be drawn as a shift to private market applications through roof top grid-connected applications is envisaged in the coming decade. In addition, the Very Small Scale Producer (VSPP) project planned to be launched in the study area due to the relative high solar energy potential.

3.2 Electricity demand and model implementation

The electricity demand in each commune of Sakonnakhon province is built up from two sectors: household and non-household. The household sector includes demand for lighting, cooling (fan), household appliances (iron, refrigerator, etc.) and entertainment (television, radio, etc.). The non-household sector included demand from small commercial enterprises e.g. tailoring, rice mills, handicraft, etc.), and institutional demands (schools, local government offices, etc.). The average household demand for different commune was estimated according to the survey carried out by PEA in 2008 at Sakonnakhon province. Table 1 shows the usage pattern of electrical appliances, in hours per day, and penetration rate determining the household demand.

Table 1. Electricity consumption per household

Appliance	Description/ Consumption (kWh/day)	Penetra -tion rate (%)	Consumption per household (kWh/year)
Indoor lights	4x36 W bulbs, 5 hrs/day	100	259.2
Outdoor lights	4x18 W bulbs, 5 hrs/day	100	129.6
Television	1x110 W, 3 hrs/day	100	9.9
Floor fan	3x55 W, 5 hrs/day	40	119
Ceiling fan	1x53 W, 3 hrs/day	40	23.0
Water heater	1x3000 W, 1.3 hrs/day	30	421.2
Refrigerator	1x60 W, 24 hrs/day	100	518.4
Iron	1x1000 W, 0.57 hrs/day	80	153.6
Rice cooker	1x450 W, 0.29 hrs/day	60	26.0
Radio/Stereo	1x1000 W, 0.57 hrs/day	50	96.0
Miscellaneous	1x100 W, 0.29 hrs/day	50	4.8
		E_t = 1760.7	

Source: PEA (2008)

[2] Data obtained from http://www.dopa.go.th/xstat/popstat.html (December 2008)

The electricity consumption of commercial (small industry, handicraft and service), and public sector is categorized as non-household energy consumption (hospitals, schools, street lighting, etc.). In this study, only institution and small industry loads were considered. Other huge loads and the point loads like agricultural loads were not considered due to the data constraint.

The results obtained using the methodology was presented via an innovative map. Fig. 4 shows the electricity demand map of Sakonnakhon province. The maximum demand of electricity lies between 29.3-60.9 GWh/year and the minimum energy demand is within 0-2.3 GWh/year as shown in the figure. From the map as shown in Fig. 4, the electricity demand scenario of the location can easily be understood.

Fig. 5 shows the available areas for estimating resource potential from solar PV. It shows that all the areas of a location cannot be used to estimate the resource potential. After finding the available areas, solar resource potential of the study area was calculated. Assumption was made that 70% of the available areas are covered by solar PV panels. Fig. 6 shows the solar resource potential of villages in a GIS map. The mean value of solar energy potential density has been termed as good. It shows that though all the areas have the same solar radiation but it is not possible to harness the energy from all over as the solar panels cannot be installed in all places. Only a few areas have solar energy resource density above 18 GWh/day.

Technical potential areas for installing PV system are located by overlaying the solar resource potential map. Fig. 7 shows the areas where there is good solar potential. The areas shown as good have solar resource potential of 18 GWh/day or more. Preferences were given based on energy demand, resource potential and population density. This means the first preference has excellent solar potential and requiring maximum energy demand.

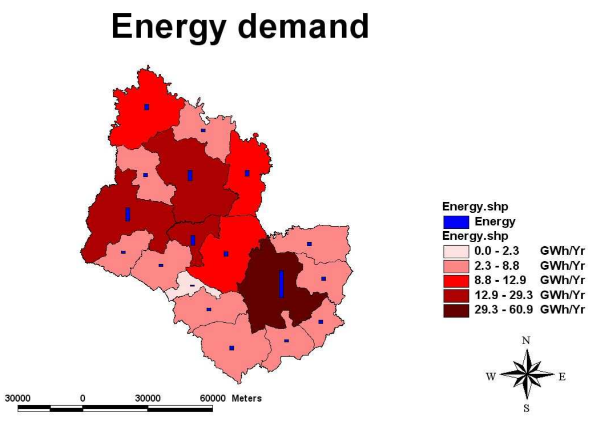

Fig. 4. Energy demand of the study area.

After locating the suitable area for installing PV system, the electricity demand of those areas was then worked out using the energy demand map. According to the defined criteria of annual electricity demand, solar resource potential and the population density, there are 27 villages which are favorable for installing PV system namely Dongmohtongtai, Huailua, Nongbuasim, Nongkwang, Thakon, Nongwangtai, Banlao, Nongpan, Tat, Wanonniwat, Kuakai, Akart, Kamsaard, Nongsanom, Duasrikanchai, Bongtai, Panna, Muangkai, Pothipaisan, Nongluang, Wattana, Tankon, Bongnhua, Palho, Tasila, Warichaphum and Kudbak proved to be technically viable. The total area was 714.4 km^2.

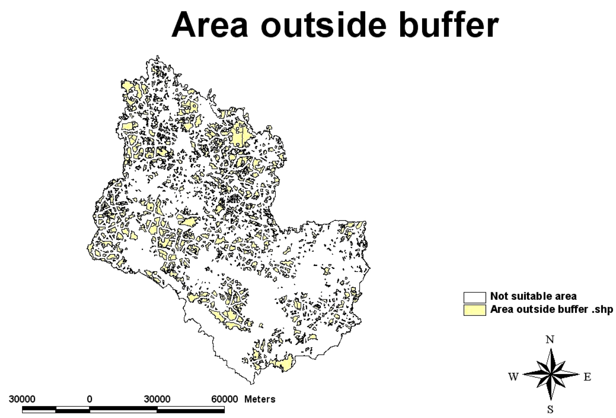

Fig. 5. Available area for installing solar panels.

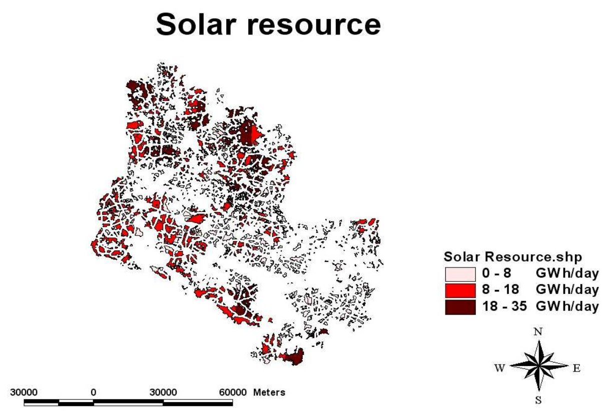

Fig. 6. Solar resource potential of the study area.

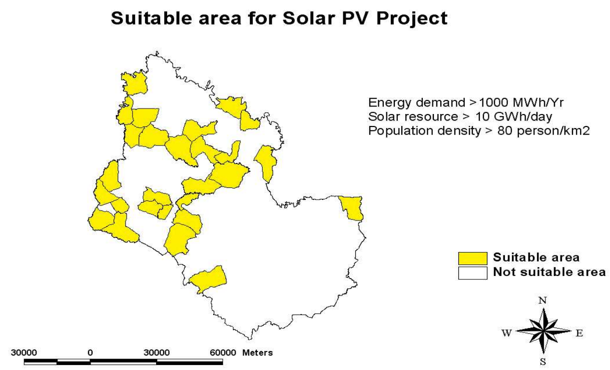

Fig. 7. Technical potential areas for installing PV system.

The system which has the lowest levelized electricity cost was chosen for estimating the life cycle cost. The expected PB for the above sites has been estimated taking into account the installation costs (solar module price, battery price, foundation costs, infrastructure cost and transportation cost), the operational and maintenance cost and electricity selling price. For estimation of PB and unit energy production cost the investment life time has been considered as 25 years. For this study no grant was considered. The payback period of the favorable site was found to be 35 years.

4. SENSITIVITY ANALYSIS

The methodology can also help to analysis different scenario which could be change due to policy change or increasing load demand. The profitability of any project is largely depending on certain parameters that could vary when the project is implemented. To assess the effects of the changes in these parameters to project, the sensitivity analyses were carried out in this study to the scenario of what-if, the energy demand is increased. The details of the analysis are discussed in this section.

Sensitivity analysis was done to see the effect of different energy demands on the suitable area to be installed a PV system. Table 2 gives the values of suitable area for different electricity demands. If the criterion of the electricity demand of the area increases, the suitable areas for installing PV system are decreased.

Table 2. Suitable area to be installed PV system for different energy demands

Energy demand (MWh/yr)	Solar resource potential (GWh/day)	Population density (person/km^2)	Suitable area (km^2)
1000*	10	80	714.4
2000	10	80	264.4
3000	10	80	74.3

* *Base case*

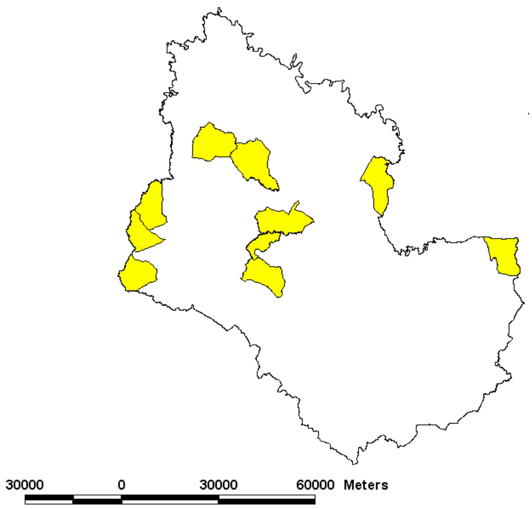

Fig. 8. Sensitivity analysis for energy demand of 2000 MWh

As can be seen from Fig. 7, according to the defined criteria of annual energy demand (1000 MWh/year), solar resource potential (10 GWh/year) and the population density (80 person/km^2), 27 villages are favorable for installing PV system with the total area of 714.4 km^2.

Fig. 8 shows the technical potential areas for installing PV system when the energy demand is increased by double with the same criterion for the solar resource potential and the population density. There are 10 villages are favorable for installing PV system namely Banlao, Tat, Akart, Kamsaard, Duasrikanchai, Bongtai, Muangkai, Pothipaisan, Bongnhua and Palho. The total area in this case was found to be 264.4 km^2.

Fig. 9 shows the technical potential areas for installing PV system when the energy demand is increased by three times of the base case with the same criterion for the solar resource potential and the population density. There are 3 villages are favorable for installing PV system namely Akart, Muangkai and Palho. The total area in this case was found to be 74.4 km^2.

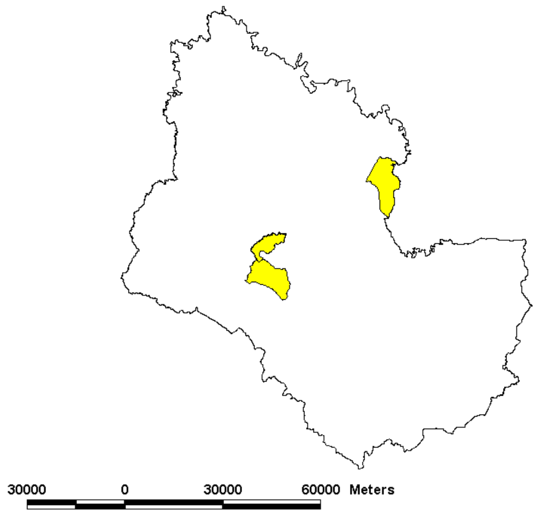

Fig. 9. Sensitivity analysis for energy demand of 3000 MWh

5. CONCLUSION

Geographic Information System is currently being used to analyze the potential for renewable energy as a source for producing electricity around the world. Many models are being developed to aid in planning for renewable technology to replace existing fuel sources or to be introduced into rural areas with no current electrical infrastructure [16]. These analytical tools are advantageous for use by policy-makers, utility companies, planning commissions, and environmentalists [17].

As the proposed model and the results are based on GIS, it is easy for the planners and project developers to visualize the results. The output of the proposed model would help the project designers to select suitable sites for solar PV system. In addition, policy makers and planners could use this method as a decision support system for estimating the load demand, technical and financial viability of these through easy visualization and could analyse either an installed project or a new project to be considered for implementation. In addition, it also shows the application of the method, clearly showing the applicability of the developed method using a suitable tool for assessing solar PV system.

The reliability of the modeling results are crucially dependent on the quality of the input data in terms of spatial resolution, accuracy, actuality and other typical GIS data parameters. In this paper, the possible renewable resource of solar PV power is considered to meet the arising future energy demands in the selected areas. A scenario setup is strongly dependent on the geographical relations of energy demand, land use and solar potentials.

A scenario analysis was also carried out which shows that the model can consider the changes in energy policy (e.g. providing incentive for RE project, capacity development for reducing O&M cost, etc.) or demand of the region/location. The process of assessing solar resource adapted in this study using technical and financial analysis can serve as an example to investigate renewable energy resources and integrating the resource with the demand.

The advantage of using GIS technology in energy studies is its flexibility in handling data available on different levels of spatial analysis and its ability to focus the spatial interrelation between the datasets. GIS also can play a significant role as a decision support tool for assessing the potential of solar PV and other renewable energy systems. Therefore, a methodology using GIS tools to assist in the identification of possible potential areas for electrification using renewable energy technologies need to be developed.

The results can help the energy planner to select suitable areas for solar PV project implementation. In addition, policy makers and planners could use this method as a decision support system for estimating the load demand, technical and financial viability of these through easy visualization and could analyse either an installed project or a new project to be considered for implementation. This method can further be extended to conduct a comprehensive study for national level in order to grasp the total RE potential and load demand of a country.

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REFERENCES

[1] Domínguez J, Amador J. Geographical information systems applied in the field of renewable energy sources. Computers & Industrial Engineering 2007;52 (3):322-6.

[2] Voivontas D, Assimacopoulos D, Koukios EG. Assessment of biomass potential for power production: a GIS based method. Biomass and Bioenergy 2001;20 (2):101-12.

[3] Shrestha RM, Kumar S, Martin S, Limjeerajarus N. Role of Renewable Energy for Productive Uses in Rural Thailand. Asian Institute of Technology, 2006.

[4] Phuangpornpitak N, Kumar S. PV hybrid systems for rural electrification in Thailand. Renewable and Sustainable Energy Reviews 2007;11 (7):1530-43.

[5] Phuangpornpitak N. Renewable Energy Options for an Island Community. Energy Security and Climate Change (ESCC 2008). Bangkok, Thailand, 2008.

[6] Akella AK, Sharma MP, Saini RP. Optimum utilization of renewable energy sources in a remote area. Renewable and Sustainable Energy Reviews 2007;11 (5):894-908.

[7] Phuangpornpitak N, Kumar S. PV hybrid system optimization for an island community. ISES Solar World Congress 2007. Beijing, China, 2007.

[8] Kusre BC, Baruah DC, Bordoloi PK, Patra SC. Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). Applied Energy 2010;87 (1):298-309.

[9] Phuangpornpitak N, Sripadungtham P, Srichatrapimuk V, Suwannakum T. Studies of Energy Management by Control Models for a Photovoltaic System in a Rural Area of Thailand. International Photovoltaic Science and Engineering Conference (PVSEC-14). Bangkok, Thailand, 2004.

[10] Kaijuka E. GIS and rural electricity planning in Uganda. Journal of Cleaner Production Optimising Reform: The Sustainability of Electricity Market Liberalisation in Less Developed Countries 2007;15 (2):203-17.

[11] Pillai IR, Banerjee R. Methodology for estimation of potential for solar water heating in a target area. Solar Energy 2007;81 (2):162-72.

[12] Gastli A, Charabi Y. Solar electricity prospects in Oman using GIS-based solar radiation maps. Renewable and Sustainable Energy Reviews 2010;14 (2):790-7.

[13] Martins FR, Pereira EB, Abreu SL. Satellite-derived solar resource maps for Brazil under SWERA project. Solar Energy 2007;81 (4):517-28.

[14] Súri M, Huld TA, Dunlop ED, Ossenbrink HA. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy 2007;81 (10):1295-305.

[15] Carsjens GJ, Ligtenberg A. A GIS-based support tool for sustainable spatial planning in metropolitan areas. Landscape and Urban Planning 2007;80 (1-2):72-83.

[16] Connolly D, Lund H, Mathiesen BV, Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. Applied Energy 2010;87 (4):1059-82.

[17] Voivontas D, Assimacopoulos D, Mourelatos A, Corominas J. Evaluation of Renewable Energy potential using a GIS decision support system. Renewable Energy 1998;13 (3):333-44.