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GHG Emission and Cost Performance of Life Cycle Energy on Agricultural Land Used for Photovoltaic Power Plant

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ABSTRACT

The research aims to analyze land use from agricultural land for photovoltaic power plant construction and electricity generation. Geographic information system technology was used to analyze and decide the suitability of the land for a photovoltaic power plant. GHG assessment and life cycle cost (LCC) were applied in this study which covered 4 processes: Land preparation, logistics, construction and system installment, and electrical generation. The research found that the maps showed the area to be moderately abundant clay, outside the irrigated area, the average rainfall was 1,100 mm./year and agriculture is only possible 4 months per year. The average solar irradiance was 17.6 W/m^2.d for this area which is suitable for building a photovoltaic power plant. CO_2 emissions for land preparation, transportation, construction and electrical generation were 0.148 tCO_2eq/kWh, 0.196 tCO_2eq/kWh, 0.418 tCO_2eq/kWh and 6.932 tCO_2eq/kWh, respectively and the net CO_2 emission was −0.549 $kgCO_2eq/kWh$. LCC for 25 years is 169.79 million baht and the cost of energy is 4.12 baht/kWh. The empirical results show that land use assessment of agriculture for the photovoltaic power plant was appropriate and worth wile without affecting the environment and economy.

Keywords: Greenhouse Gas, Geographic Information System, Land Use, Life Cycle Cost, Photovoltaic Power Plant
JEL Classifications: C8, G0, M2

1. INTRODUCTION

In the past decade many researches have focused on the suitable land use by considering the especial diagnostics, following their objectives. Land is used in multiplicity according to variety of human needs and to serve numerous, diverse purposes. When the users of land decide to employ its resources towards different purposes, land use change occurs producing both desirable and undesirable impacts. The analysis of land use change is essentially the analysis of the relationship between people and land. Why, when, how, and where does land use change happen? (Mohit and Rajan, 2014). The major reason was because of severe drought in Thailand. The Thai government introduced agricultural zoning for six main crops such as rice, tapioca, maize, sure cane, rubber and oil palm. This is aimed at boosting income and lowering the burden of long-term subsidies. The six main crops were vital contributors to the country's economy (Food Agriculture Organization, 2015). Therefore, Phetchabun province made the agricultural development plan (zoning) in order to boost the agricultural productivity on a target area and to change other crops on non-target areas (Food Agriculture Organization, 2015). Phetchabun province has initiated management of crop zoning such as rice, tapioca, maize, sugar cane, rubber, pineapple and longan (Food Agriculture Organization, 2015). This research was conducted in order to investigate and analyze the land use change from agriculture to photovoltaic power plants which were expanding under the renewable energy and alternative energy development plan. Main target for consideration of economic crop cultivations were paddy, sugar cane, maize, cassava and para rubber. Geographic information system (GIS) were applied to evaluate the suitability of photovoltaic power plants (Stanford University, 2005; Supoch, 2015; Wiwat, 2014). Life cycle cost (LCC), and sensitivity analysis were used to evaluate economic performance. Meanwhile, the life cycle assessment (LCA) was used to evaluate GHG emission of photovoltaic the power plant. Consequently, these methods were integrated to apply as a tool which considered the target area for photovoltaic power plant construction.

2. ANALYSIS PROCESS

From Figure 1 the methodology of the study can be explained as follows.

2.1. GIS

GIS was used to indicate maps of the land use of the five economic crops in order to find the non-target area.

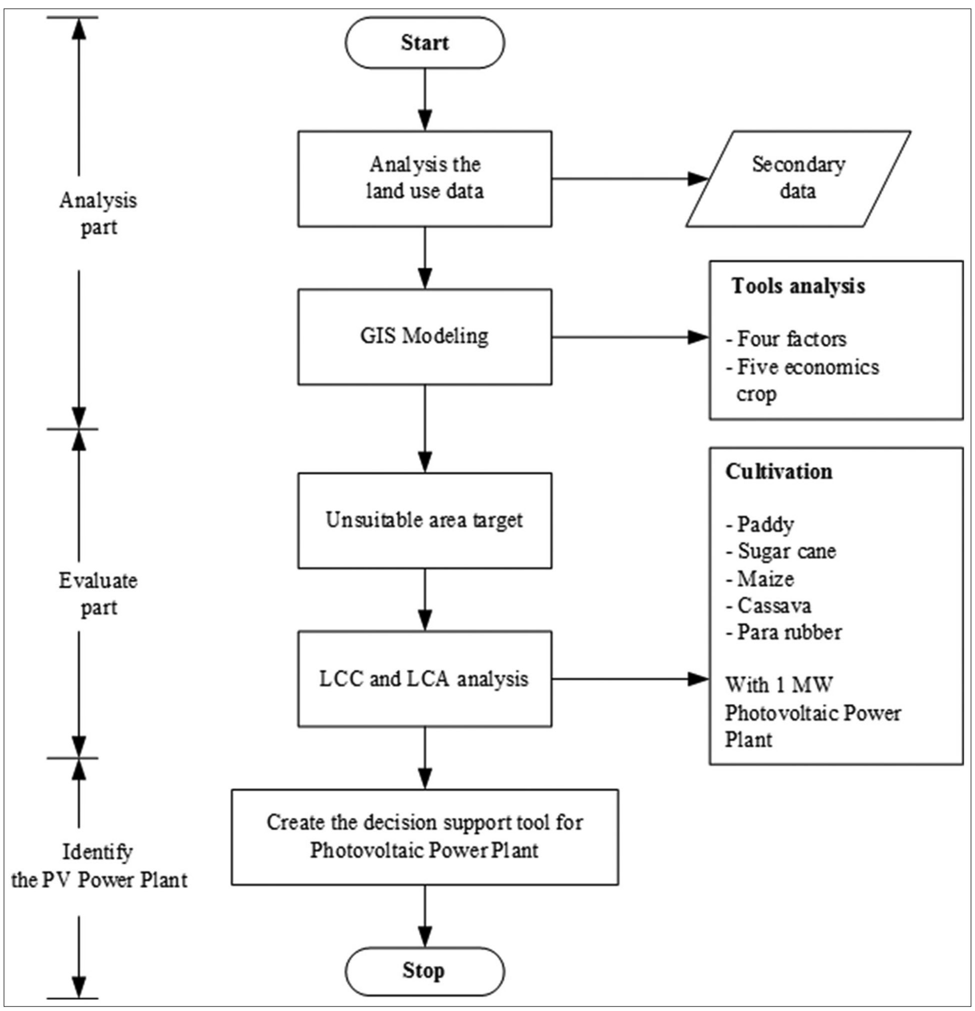
2.1.1. Study area

Phetchabun lies in the lower northern region of Thailand. With borders on three regions, the North, the Central and the Northeast. The central part of the province lies on the Pa Sak River with mountain ranges running along both the eastern and western sectors. Because of the fertility of the land, Phetchabun has always been an agriculturally productive area. Phetchabun has an area of about 7,712,299 rais (12,339.68 km^2) and this study considers the land use on agricultural area only about 3,145,872 rais (5,033.40 km^2). Phetchabun is divided into the following districts: Muang, Lom Sak, Lom Kao, Chon Daen, Nong Phai, Wichian Buri, Si Thep, Bueng Sam Phan, Wang Pong, Nam Nao and Khao Kho.

2.1.2. Implement

1. Map of Thailand 1:50,000
2. Hardware and Software
   - Software QGIS system (version 2.14.3) is used for analysis and indication of the results in a spatial map
   - Microsoft excel program is used to conduct and edit the data to development the spatial data base.
   - SPSS program is used for analysis of the statistical data.
3. Data
   - Spatial data
     - Soil view version 2.0 from Land Development Department
     - Terrain elevation A.D. 2013 from Consortium for Spatial
     - Information (CGIAR-CSI)
     - Meteorological data from Meteorological Department of Thailand
     - Land use data A.D. 2010 from Land Development Department
   - Attribute characteristics
     - The average annual rainfall data A.D. 2003-2013 from the Meteorological Department of Thailand
     - Property of soil data A.D. 2005 from the Land Development Department

Figure 1: Methodology of research



2.1.3. Operation procedure

1. Reviewed the literature about important factors of economic crops namely paddy, sugar cane, maize, cassava, and para rubber by considering the four diagnostic factors namely, climate factor (Clim), soil chemical property factor (Chem), soil physical property factor (Phys) and topography factor (Topo) for suitably analysis in GIS modelling (Office of Agricultural Economics, 2013; Chada, 2013; Thanyalak and Kanlaya, 2014; Chiramakara and Thanarak, 2016).
2. Brought the four diagnostic factors to overlay in GIS modeling
3. The areas of five economic crops were labeled as (S1), (S2), and (S3) for high, moderate and unsuitable respectively in terms of land suitability. (Thanyalak and Kanlaya, 2014, Chiramakara and Thanarak, 2016, Office of Agricultural Economics, 2014)
4. Made a new map and computed the new non-target areas (S3*) from intersection of five non-target areas (S3)
5. Overlaid solar radiation data with the new non-target area data (S3*). For the above steps, GIS analysis is shown in Figure 2.

The new non-target areas in Phetchabun province were investigated for intensity of solar radiation by overlaying the solar data with the new non-target areas data. The result is shown in Figure 3. The new non-target areas have average solar radiation about 17.88 MJ/m^2.day which is a moderately suitable value (Puvadol and Supaporn, 2015) for photovoltaic power plant construction.

From Figure 3, it can be seen that Wichian Buri and Si Thep district has average solar radiation about 20.1 MJ/m^2.day, Bueng Sam Phan, Nong Phai and Chon dan districts have average solar radiation about 18.67 MJ/m^2.day, Mueang Phetchabun and Wong Pong district have average solar radiation about 17.53 MJ/m^2.day, Khao kho and Lom Sak have average solar radiation about 16.81 MJ/m^2.day whereas Lam Kao and Nam Nao have average solar radiation about 15.82 MJ/m^2.day. Therefore, the non-target area (S3*) in Wichian Buri and Si Thep district has the highest suitablility for construction of photovotaic power plant and the total area available is about 11,764 rais ($18.82 \times 0^6 m^2$). Bueng Sam Phan, Nong Phai and Chon dan district has morderate suitablility

Figure 2: Geographic information system analysis of five economic crops

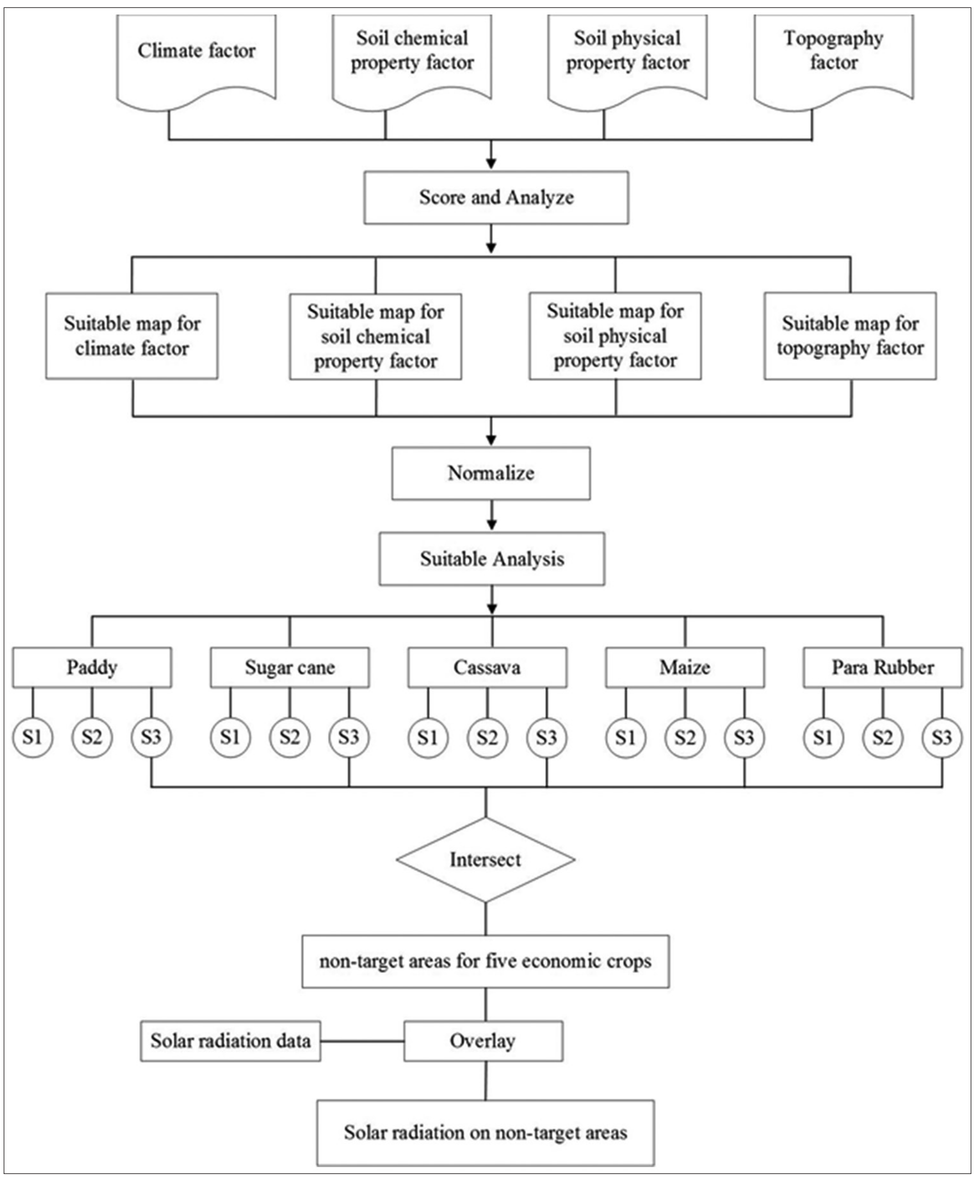
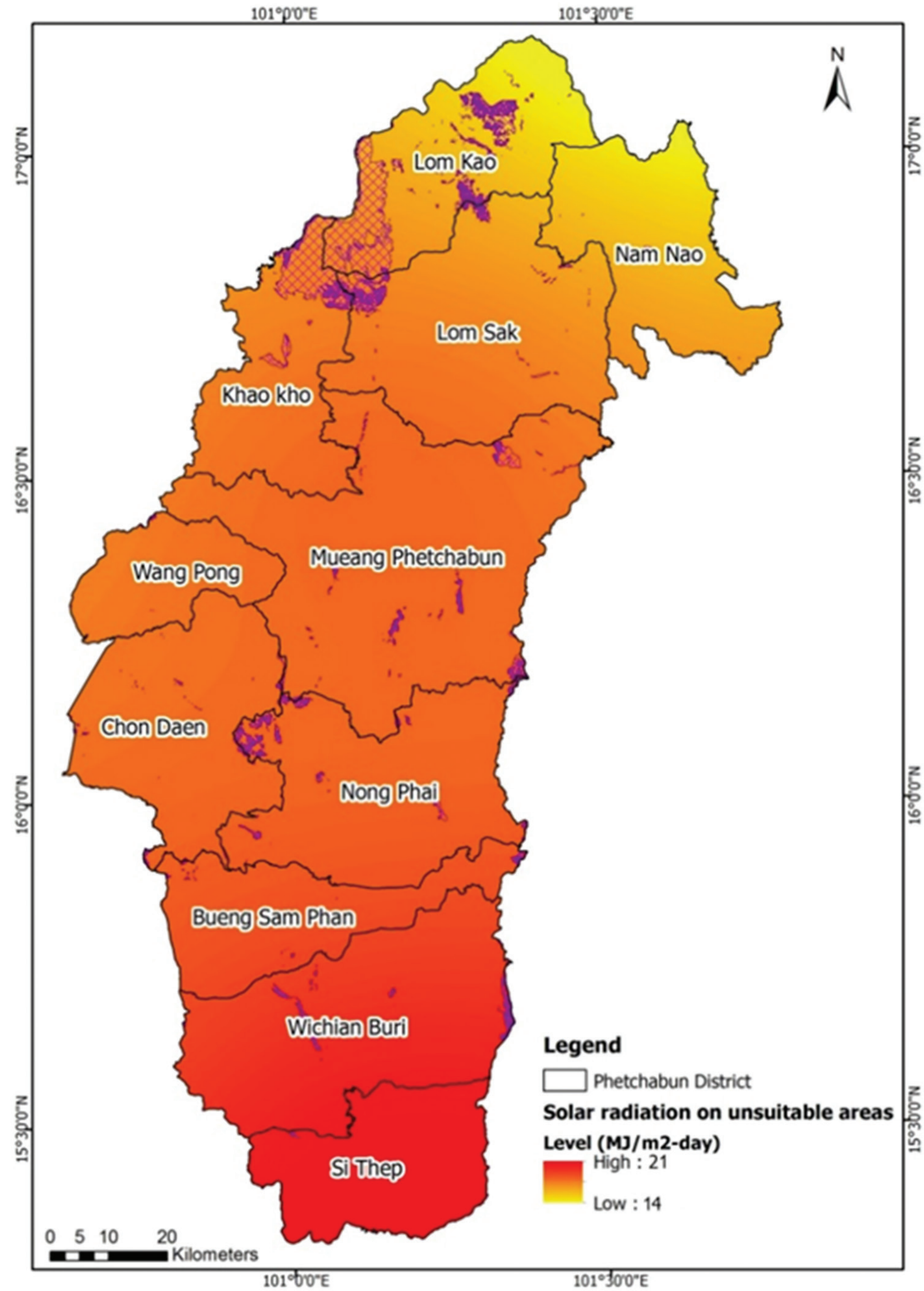


Figure 3: Solar radiation on the new non-target areas



to build photovotaic power plants and the total area is about 23,379 rais (37.4×10^6 m^2). In these five districts the non-target areas can be changed to build photovotaic power plants of about 3500 MW capacity.

2.2. LCA for GHG Emission

LCA (LCA, also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis) is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacturing, distribution, use, repair and maintenance and disposal or recycling) (Elena et al., 2015) Umberto et al. (2012) evaluated the environmental impact, and therefore the actual sustainability of this technology, examining a ground-mounted 1778.48 kWp photovoltaic plant, realized by TerniEnergia S.p.A., located in Marsciano (Perugia, Italy). The analysis was conducted using the methodology of LCA, which allows to consider all stages of the life cycle, from the extraction of raw materials to the plant's disposal ("from a cradle to grave perspective"). In particular, the study took into account the soil preparation, the installation of fence and electrical substations of low and medium voltage, the mounting of support structures, also with reference to hot dip galvanizing process, the production of modules, their installation, the wiring apparatus and the network connection. The transport of all components to the installation site was considered for each stage that was examined. Finally the use of photovoltaic plant technology presented important environmental benefits in comparison with traditional energy production systems.

The analysis was carried out according to UNI EN ISO 14040 and UNI EN ISO 14044, which regulated the LCA procedure. The LCA modeling was performed using SimaPro software application and using Eco Indicator 99 methodology. The results of the analysis depicted some important parameters like, EPBT was equal to 4.17 years, EROEI was equal to 4.83 and CO_2 emissions and GWP100 was 88.74 g/kWh. R. Garcı´a-Valverde et al. (2009) studied energetic and environmental LCA of a 4.2 kWp stand-alone photovoltaic system at the University of Murcia (south-east of Spain). The energy pay-back time was found to be 9.08 years and the specific CO_2 emissions was calculated as 131 g/kWh. The daily constant load pattern was such that the annual energy consumption came out to be 5,028.24 kWh_{el}/year. On the basis of the LCA, it was found that the facility has about 45.692 MWh_{el} of embodied energy and 13.166 metric tons of embodied CO_2. Transportation only accounts for 0.11% and 1.7% of the total embodied energy and embodied CO_2, respectively. Recycling accounts for 2.1% and 3.67% of the total embodied energy and the embodied CO_2 respectively, but only batteries, PV modules frames, supporting structure and cables can be recycled for the moment in Spain. Therefore, 430 kg of waste from PV modules and electronic devices must be land filled at the decommissioning phase. Elena et al. (2015) evaluated the main cost drivers environmental and economic effects of five widely diffused and market-valued agricultural productions (organic tomato and pear, integrated wheat, apple and chicory) and combined the results in order to understand the long-term externalities and impacts of agricultural productions. Khaenson et al. (2017) found an impact both human health and ecosystem quality after analyzing the 1 kWh solar power generation.

Data obtained in local assessment showed a wide margin of improvement of resources management at the farms level in the short-term, but also allowed for the investigation of future effects of environmental impacts not expressed in product price on the market. Reaching a real sustainable model for agriculture could be a value added approach firstly for farmers, but also for all the people who live in rural areas or use agricultural products.

In conclusion, to understand GIS, LCC, LCA principles, there are various guidelines to use these technologies for each objective. GIS was used to display spatial maps of the objective as it was easy to understand and analyze. LCC was used to evaluate the economic performance of projects in order to know the viability of projects. LCA was used for evaluation of environmental impact in terms of CO_2 emission for each project by considering the different scopes. Therefore, this study used these technologies as principles successfully for selection of an area to change from economic crop cultivations to photovoltaic power plant construction.

To calculate CO_2 emission of 1 MW photovoltaic power plant the following the Figure 4, formula was used (Thailand Greenhouse Gas Management Organization, 2015)

$$CO_2 \text{ emission} = EF \times AD \quad (1)$$

Where
CO_2 emission = The amount of CO_2 emission ($kgCO_{2eq}$)
Emission factor (EF) = The CO_2 emission coefficient ($kgCO_{2eq}$/unit)
Activity data (AD) = Activity data (unit).

2.3. Life Cycle Energy Cost

LCC was used to evaluate the economic performance of photovoltaic power plant in order to find net present value (NPV) Autchara (2014), Prang and The Joint Graduate School of Energy and Environment (2012), Sukchai (2011), Varawoot (2018). LCC Assessment of the photovoltaic power plant, shown in Figure 5, has been done considering its electricity generation.

Figure 5 shows the electrical generation system that includes solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, a transformer to change high voltage to low voltage, as well as mounting, cabling and other electrical accessories to set up a working system. To gather cost/income of the photovoltaic power plant, construction data presented in Tables 1 and 2 was used.

With the NPV calculated for each alternative, comparisons are simple because units are consistent. The best option is simply the alternative with the lowest LCC or NPV.

The basic formula is as follows:

$$LCC = C + PV_{RECURRING} - PV_{RESIDUAL\text{-}VALUE} \quad (2)$$

Where
LCC = The LCC
C = The year 0 construction cost (hard and soft costs)
$PV_{RECURRING}$ = The present value of all recurring costs (utilities, maintenance, replacements, service, etc.)
$PV_{RESIDUAL\text{-}VALUE}$ = The present value of the residual value at the end of the study life

Project costs that occur at different points in the life of a project cannot be compared directly due to the varying time value of money. They must be discounted back to their present value through

Table 1: The details of 1 MW photovoltaic power plant construction data 1.435 MWh/year

Description	Value range
Work in year (G-power, 2013)	365 days
Life time in year (G-Power, 2013)	25 years
Final yield (PVsyst)	3.93 h/day
Installed capacity	1 MW
Produced energy (PVsyst)	1.435 MWh/year
Electricity price (FIT) (EPPO, 2015)	5.66 Baht/kWh
Proportion of loans in fixed cost	100%
Discount rate (MRR) (Kasikorn Bank, 2015)	7%
Project area	10 rais (3.95 acres or 16,000 m^2)

Figure 4: Life cycle assessment of 1MW photovoltaic power plant

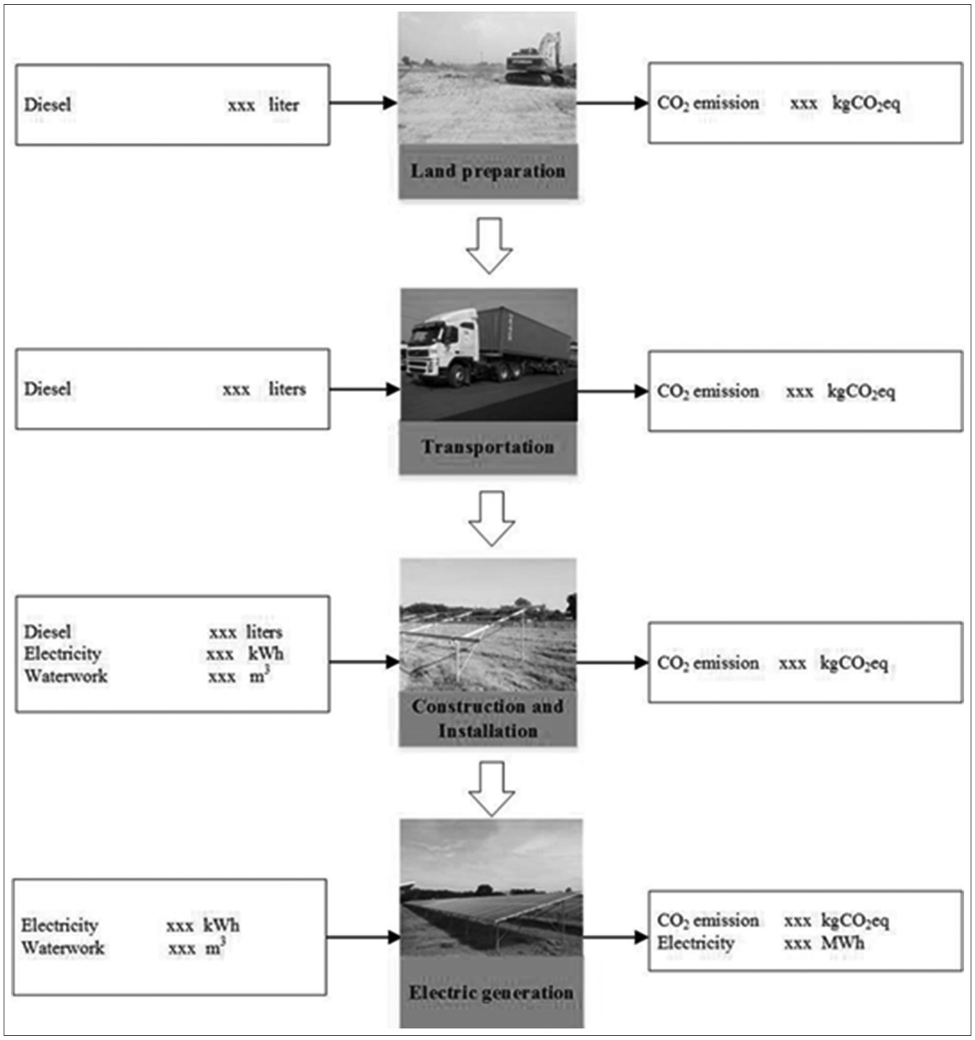
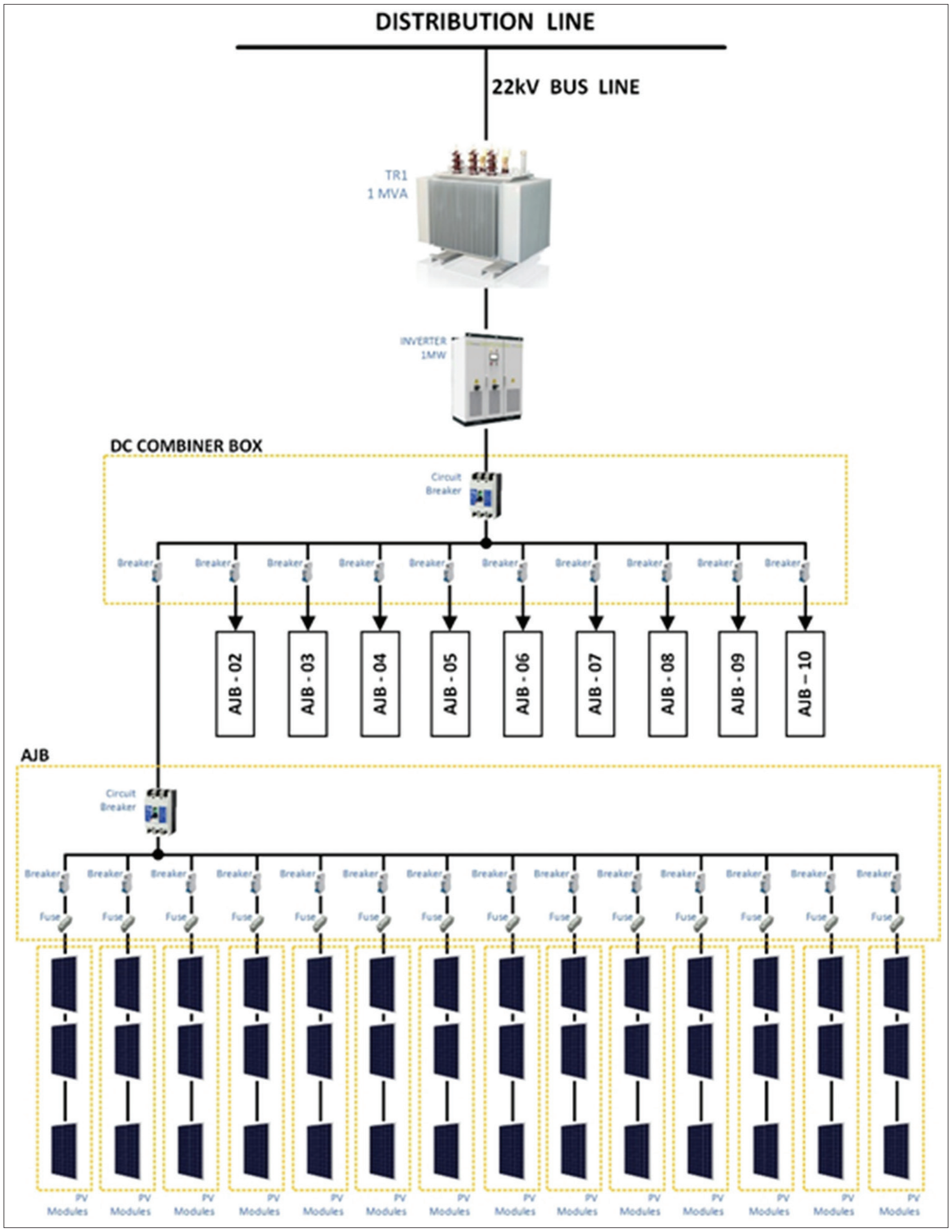


Table 2: Cost/income of 1 MW photovoltaic power plant for a 25-year lifetime

Items	Description	Quantity	Value (Baht)
Fixed cost	Solar modules	1 MW	30,000,000
	Inverter and monitoring	1 MW	3,000,000
	DC Combiner	1 set	600,000
	Transformer	1 set	1,500,000
	Supporting structure	1 set	4,000,000
	Electrical construction	1 set	2,400,000
	Civil engineering	1 set	1,000,000
	Building construction	1 set	1,000,000
	General administration		500,000
	Project area	10 rais	1,500,000
	Total fixed cost		45,500,000
Operation cost	Management salary	Increase 3% every year	180,000
	Engineer salary	Increase 3% every year	240,000
	PEA service free (2%)	Every year	659,058
	Communication	Every year	50,000
	Entertain	Every year	100,000
	Gasoline	Every year	50,000
	Maintenance labor	Increase 3% every year	384,000
	General service	Every year	98,859
	Inverter replacement	At 15^{th} year	2,000,000
	Insurance (0.15%)	Every year	49,429
	Others	Every year	50,000
Salvage value	10% of fixed cost	At 25^{th} year	4,550,000

Figure 5: The diagram of 1 MW photovoltaic power plant



the appropriate equations. The discount rate is defined in terms of opportunity cost. The basic discount equation is as follows:

$$PV = F_Y/(1+DISC)^Y \quad (3)$$

Where

PV = The present value (in year 0 bahts)

F_Y = The value in the future (in year Y bahts)

DISC = The discount rate

Y = The number of years in the future.

3. RESULTS AND DISCUSSIONS

3.1. Assess the Land Use Change of the Five Economic Crops through GIS for Selection of Areas

GIS was used for finding the target area by considering the four diagnostic factors namely climate factor, soil chemical property factor, soil physical property factor and topography factor for suitability analysis in GIS modeling. The results found that the non-target area for five economic crops are about 263,759 rais (0.42×10^9 m^2) which are in 11 districts in which Lam Kao has the most non-target area about 117,582 rais (0.19×10^9m^2) and Si Thep has the least area about 425 rais (0.68×10^6m^2). When five sampling coordinates were considered, it was found that the landscapes were dry land, hill and non-irrigated hence maize was planted in these areas. The cultivators could plant one economic crop on the dry land during the whole year in the rainy season only. It was found that in Wichian Buri and Si Thep districts average solar radiation was about 20.1 MJ/m^2.day, in Bueng Sam Phan, Nong Phai and Chon dan districts have average solar radiation about 18.67 MJ/m^2.day, in Mueang Phetchabun and Wong Pong districts have average solar radiation of about 17.53 MJ/m^2.day, Khao kho and Lom Sak has average solar radiation about 16.81 MJ/m^2.day whereas Lam Kao and Nam Nao has average solar radiation about 15.82 MJ/m^2.day. Therefore, the non-target area (S3*) in Wichian Buri and Si Thep districts(total area about 11,764 rais (18.82 × 10^6 m^2) has the highest suitablility for construction of photovotaic power plants. Bueng Sam Phan, Nong Phai and Chon dan districts (total area about 23,379 rais (37.41 × 10^6 m^2)) Si Thep morderate suitablility to build photovotaic power plants. Non-target areas from these five districts can be changed to build photovotaic power plants of about 3500 MW capacity.

3.2. LCA of Five Economic Crop Productions and to Evaluate Photovoltaic Power Plant

The study of environmental impacts, of economic cultivations for a 25-year lifetime by considering the four steps, including land preparation, cultivation, treatment and harvesting, showed that in all four steps mentioned above the cumulative CO_2 emission for paddy, sugar cane, maize, cassava and para rubber was 217,903.39 kgCO_2eq, 104,205.75 kgCO_2eq, 48,140 kgCO_2eq, 5,960kgCO_2eq, 7,856.2 kgCO_2eq, respectively. LCA of 1MW Photovoltaic power plant for a 25-year lifetime worked out for 4 procedures namely land preparation, transportation, construction and electrical generation was 2,056.0276 kgCO_2eq, 7,333.1435 kgCO_2eq, 20,443.0050 kgCO_2eq and 203,275.4897 kgCO_2eq, respectively and total CO_2 emission was about 233,107.6658 kgCO_2eq. When compared CO_2 emission in different stages, it was found that land preparation has the least CO_2 emission and electrical generation proceduction has the most CO_2 emission about 0.0573 gCO_2eq/kWh and 5.6684 gCO_2eq/kWh, respectively. Whereas transportation and construction procedures have 0.2045 gCO_2eq/kWh and 0.5701 gCO_2eq/kWh, respectively and the total CO_2 emission for electricity production from Photovoltaic power plantwas about 0.0065 kgCO_2eq/kWh.

Therefore, comparison of CO_2 emission of Photovoltaic power plant with five economic crops showed that GHG reduction of paddy, sugar cane, maize, cassava and para rubber were −15.20 tCO_2eq, −128.90 tCO_2eq, −184.97 tCO_2eq, −227.15 tCO_2eq, −225.25 tCO_2eq, respectively, means that land use changing from five economic crop cultivations to photovoltaic power plantcontruction had higher CO_2 emission on 10 rais non-target area for a 25-year lifetime because of paddy and maize used meterials and energy about 3–4 months/crop, cassava 8–12 months/crop, sugarcane 3–5 years/crop and para rubber used area long term cropping about 22 years/crop whereas the Photovoltaic power plant used meterials and energy for a 25-year lifetime, so the CO_2 emission of Photovoltaic power plan was more than five economic crops.

Net CO_2 emission of 1 MW Photovoltaic power plant was −0.5489 kgCO_2eq/kWh or 1 MW photovoltaic technology cloud reduce carbon dioxide equivalent of about 19,684.23 tCO_2eq for a 25-year lifetime.

Net CO_2 emission of land use change from five economic crop cultivations to Photovoltaic power plant construction found that a Photovoltaic power plant could reduce CO_2 emission on cultivation area of paddy, sugar cane, maize, cassava, para rubber equal to 19,669.03, 19,555.33, 19,499.26, 19,457.08, 19,458.98 tCO_2eq, respectively which indicated that photovoltaic technology was clean energy, more environment friendly and worth land use change.

3.3. Evaluate Economic Performance of Five Economic Crops and Photovoltaic Power Plant Construction

To study LCC on a non-target area about 10 rais (16,000 m^2) for 5 economic crop cultivations and 1 MW photovoltaic power plant construction for a 25-year lifetime it was found that life cycle benefit of paddy, sugar cane, maize, cassava and para rubber were 643,651 THB, 1,044,977 THB, 529,935 THB, 766,787 THB and 1,050,907 THB, respectively whereas the benefit for a 1MW photovoltaic power plant was 113,915,970 THB. The LCC of paddy, sugar cane, maize, cassava, para rubber and photovoltaic power plant were 839,554 THB, 1,180,795 THB, 1,116,408 THB, 799,312 THB, 1,086,176 THB and 88,090,743 THB, respectively. and the NPV of paddy, sugar cane, maize, cassava, para rubber and photovoltaic power plant were −195,903 THB, −135,818 THB, −586,473 THB, −32,525 THB, −35,269 THB and 8,419,308 THB, respectively. The results showed that NPV of five economic crops were less than zero which indicated that these cultivations should not be done in non-target area as the cost and farm price cannot be controlled by cultivators/farmers. Cultivation on non-target areas, costs higher to the farmers because the arid land treatment will be an additional expence compared to target area cultivation in order to produce high/competetive yields. Furthermore, paddy and maize take 3–4 months/crop whereas cassava takes 8–12 months/crop where cost of land preparation, planting and seeding for every new cultivation will be involved in this way they are not similar to sugarcane and para rubber which have long-term cropping around 3–5 years/crop and 22 years/crop respectively. Economic crop cultivation on non-target area depends on many factors such as climate, investment and treatment, irrespective of its loss or profit. Suitable land use will help cultivators/farmers to save cost from production factors such as fertilizer, chemical and fuel. While considering the NPV of a photovoltaic power plant it was found that NPV of the photovoltaic power plant was more than zero which indicated that investors should invest in non-target areas to get government support (feed-in tariffs).

B/C ratios of paddy, sugar cane, maize, cassava, para rubber were 0.77, 0.88, 0.47, 0.96 and 0.98 respectively which were less than one, that means investment in these cultivations should not be done in non-target areas, whereas B/C ratio of the photovoltaic power plant was greather than one (1.10) which indicated that the investment in a photovoltaic power plant should be done in this project in non-target areas.

Sensitivity analysis of economic crops by increasing income found that paddy, sugar cane, cassava and para rubber had NPV more than zero and B/C more than one when increased income equal 40%, 20%, 10% and 10% respectively and had avialable investment when decreased cost equal 20%, 10%, 10% and 10% respectively. Whereas maize was not available for cultivation when increased income and decreased cost until 50%. A photovoltaic power plant project could not decrease yearly 1% yield electricity generation because of NPV less than zero and B/C less than one that indicated to be not avialable for investment and this project could decrease sale price 5% FIT only. If decreased more than 5% FIT, this project was not avialable. In the part of discount factor found that only para rubber was avialable for cultivation when decreased discount factor to 5% whereas other economic crops were not avialable for cultivation, even decreasing the discount factor until 4%. Meanwhile, photovoltaic a power plant could increase discount factor until 8% only.

The results of switching value test indicated that five economic crops must increase income or decrease cost for avialable cultivation such as paddy must increase income more than 30.44% or must decrease cost <23.33%, maize must increase income more than 111% or must decrease cost <53% whereas cassava and para rubber must increase income or decrease cost to be not more than 5%. In the part of photovoltaic power plant can increase cost not over than 9.77% or decrease income not lower than 8.90% for feasible construction.

Hence it can be safely concluded that agricultural areas can be changed to build photovoltaic power plants which have reasonable profit and has very low impact on environment and are useful for local population and provides sustainable energy for the country.

4. CONCLUSIONS

Land use assessment is an important principle for indication of environmental, economic and social impacts. At present, agricultural areas are selected to be the first choice for construction of photovoltaic power plants. Therefore, this research integrated GIS, LCC, LCA, sensitivity analysis and switching value test as a tool which was applied to consider for changing agricultural area to photovoltaic power plant construction.

5. RECOMMENDATIONS

Since the solution depends on the specific situation, a decision support tool (DST) should be developed. DST can provide suitable development options for the photovoltaic power plant construction. These are criteria guidelines for decision making on how to select the suitable land area in order to plan and manage the land use for renewable energy development by using an integrated methodological approach. This DST indicate the beneficial result of each factor for decision making on how to select the land area and land use change from economic crops to photovoltaic power plants.

From the criteria of photovoltaic power plant construction area selection, the recommendations for improvement are listed below:

1. Modifying diagnostic factors: Addition of diagnostic factors namely distances from road and power line transmission systems and analysis of remote sensing data with GIS data for PV power plant construction should be considered to ensure precise and appropriate selection.
2. Improvement in data used in economic calculation: Accurate farm price, for instance, should be taken in to consideration because there is a variation in government's support price for different products making it difficult to plan for investment in the future.
3. Development and improvement in LCA: Consideration of GHG for economic crops, from use of energy and material with net ecosystem production that those economic crop cultivations will absorb or emit carbon dioxide between process, if an activity absorbs carbon dioxide will be called "carbon sinks" but if the activity emits carbon dioxide it will be called "carbon sources." So that we will know net emission of economic crop cultivations and land use can be compared appropriately with photovoltaic power plant construction.

6. ACKNOWLEDGMENTS

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