# CHAPTER III

# METHODLOGY

The economic analysis of photovoltaic systems are developed in response to the needs for better information on the cost of energy from renewable energy technologies and how to make effective energy investment decisions.

This information is provided by one or more quantities called economic indicators. These economic indicators are calculated by using appropriate economic analysis models (equations) for PV system. The numerical quantities required to solve these equations are compiled from the specially-developed cost and performance parameter formats for 3 photovoltaic systems.

For this research, 3 major types of photovoltaic systems, which have been successfully used for rural electrifications, were undertaken. The advantages of each photovoltaic system will be illustrated in this research by methods of benefit – cost evaluation and environmental impact under the same condition of electricity supplied by each of the following systems:

1. Stand -alone Solar Home System
2. Battery Charging Station
3. Centralized Mini-Grid

An intra-comparison of these systems will be carried out to compare with the Diesel Generator system. Data will be collected from the system installation sites around Thailand based on purposive samplings. The whole point of a model is to give a simplified representation of reality. The model system will be optimized by simulation for 1% of un-electrified households in Thailand.

The methodology for this research is indicated in the following flow chart (figure 6):

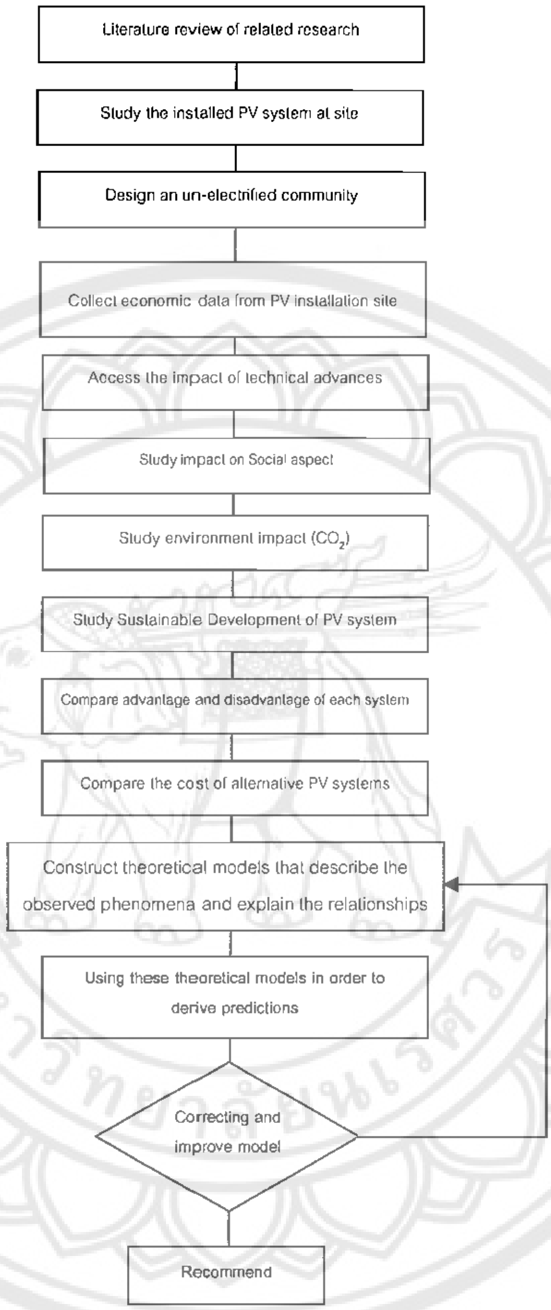


Figure 6 Methodology flow chart of this Dissertation.

## 3.1 Study the Photovoltaic System in Thailand

### 3.1.1 Solar Home System (SHS)

Solar Home system is configured for each individual household user has its own independent Solar PV system as a single independent unit. It comprises one or more PV modules, charge controller, and Balance of Systems (BOS) components which consists one or more batteries, cables, lighting fixtures, sockets that can be used for other appliances such as TV, radios etc. The system might be incorporated with DC/AC inverters for AC loads.

The Provincial Electrification Authority (PEA) of Thailand has been very much instrumental in the electrification of remote villages with SHS. At the end of 2002, they have completed the extension of electricity service to 99% of the 70,715 un-electrified households. However, there were 701 villages which were too far away from their grid networks, 549 of which are in remote, highly forested areas and other remote islands throughout Thailand. Owing to the Thai Constitutional Declaration of 1997 that directed the government for 100% electrification, the PEA had to resort to the use of SHS for the electrification of such areas.

By April 2005, the total SHS installed by PEA, excluding the two pilot projects, amounted to 153,000 each with a 120 Wp PV module; thereby amounting a total installed capacity of 18,360 kWp. This was just the first phase of the Thai Government's Mega Electrification Program. Contracts were awarded to five (5) companies for the installation of the SHS systems. A total of four (4) billion Thai Baht was paid to these companies for the execution and completion of this 1st phase [Photon International; June 2004, p.78]. The distribution of the contracts is shown in the table below.

Table 3 First Phase Shares of Contract for the Installation of the Thai SHS Project

| Zone | Company | No. of SHS |
|---|---|---|
| 1 | Acumen Consulting * | 32,663 |
| 2 | Solartron | 33,547 |
| 3 | Bangkok Solar | 21,815 |
| 4 | SP Secco * | 24,077 |
| 5 | Solartron | 20,853 |
| 6 | Power Line Engineering * | 20,045 |
| Total | | 153,000 |

* = System designed and BOS supplied by the company, Solartron supplied the PV modules

It can be seen from the above table that Solartron supplied 54,400 (i.e. 35.56%) of the SHS, at the price of 25,000 Thai Baht per system; and as such had a lion's share of the total budget since they are the principal supplier of the Solar PV modules to the other companies.

As much as there haven been successes with SHS electrification, it is not free from unforeseen problems. A recent survey was conducted by Chiang Mai University on behalf of PEA to assess the performance of SHS. Of the 74,659 SHS surveyed, 1,291 (i.e. 1.73%) of them are not in good working order.

In this regards, the author has visited some of the selected sites of SHS installation areas around Thailand to interview the end users regarding the system performance, reliability of the system and social impacts from the system which are discussed later in this chapter.

3.1.2 Battery Charging Station (BCS)

The Battery Charging Station (BCS) consists of an array of PV module equipped with battery chargers, which are used to charge a bank of car/ solar batteries in a battery charging station. The size of the station depends on the number of households' in a village. The users have to carry their batteries to the charging station in the morning for charging their battery/batteries by the solar PV battery charging station - for a certain fee- during the day; and then carry them again to their respective homes in the evening in order to light up one or two low energy fluorescent lamps. The batteries can be used for about 3 – 4 hours in the evening and can be recharged after every 3 or 4 days. The state of charge of the battery in each household is monitored by an indicator informing the user as when to the battery should be taken for recharging.

In Thailand, battery charging stations (BCS) were the first forms of de-centralized electrification system used for electrifying the very remote villages, especially those in the Northern remote areas of the country.

All the Battery Charging Stations were installed by the Public Works Department (PWD) under the Ministry of the Interior, and the Department of Alternative Energy Development and Efficiency (DEDE) under the Ministry of Energy with capacities ranging from 1.5 – 4.5 $kW_p$. By 1997 there were 1,392 BCSs installed [EPPO/DANCED, 1998; p.9] declining now to 362 systems operating in the whole country. The decline is due to result of several factors which are given below:

1) The BCSs were fully government funded projects whose funding – Including heavy subsidies- depended upon the state budget. After the 1997/98 economic crisis, funding for such projects were slashed considerably (by 40% for DEDE projects) leading to a sudden drop in demand.

2) The structural management of these systems in these remote areas was Not created in projects funded by the PWD. The reporting structure for problems with the system was too centralized in Bangkok and was fully dependent on the decisions of sending technicians to check and report the problems were being undertaken. This had created long delays in carrying out maintenance works and thus making people losing faith in the system. However, those projects carried out by DEDE were managed by the local villagers by themselves and were running well.

3) Management boards were formed, which determine charging fees, battery charging cycle, purchasing of distilled water and even cost of battery. They also organize tree cutting around the PV panels to prevent shadowing of PV array and allowance for workers of the charging stations [DEDE; p.1&2].

4) The growth of the installation of Solar Home Systems in these areas led to people switching to self-generated and independent electricity which saves them the burden of carrying their batteries to and from BCS.

3.1.3 Centralized Mini-Grid (CMG)

The centralized Mini-Grid system consists of inverter and battery with low-voltage distribution system (380 VAC) of 3 phases AC supply. The electrical load to the household which are located not far more than 1500 meter from PV centralized system the CMG serves the best. The CMG were designed for the household having average load of 400 Wp/day while the electricity appliances are AC type.

Very few CMG demonstrations systems are deployed in Thailand, one of which being located at the School of Renewable Energy Technology (SERT), Naresuan University, with the high performance and quality equipment for research purpose compared to actual system installed in real site.

### 3.2 Load Demand Analysis

For a typical rural household, the energy consumption is shown in the Table 4 with operation times based on estimations by compiled by the PEA [Kruangpradit, P. et al, 2002; p.5]:

Table 4 Daily energy consumption of electrical appliances

| Electrical appliances | Rating (W) | Operating hours (hr/day) | Energy Consumption (Wh/day) |
|---|---|---|---|
| Fluorescent Tube 1 | 10 | 4 | 40 |
| Fluorescent Tube 2 | 10 | 4 | 40 |
| Color TV 1 | 60 | 3 | 156 |
| Video CD Player | 25 | 1.5 | 37.5 |
| Total | 105 | | 297.5 |

Electricity Demand Forecast for Rural Community

To forecast the electricity consumption in rural area with various of photovoltaic systems, in this study present the percent change or growth rate of electricity demand base on demand equation [Electricity Development Department report, PEA, April 2004, p.4-3 – 4-4];

$$D_t = D_{t-1}(1 + \%\alpha\Delta n_t + \beta\%\Delta i_t + e_t^y\%\Delta y_t + e_t^p\%\Delta p_t) \qquad (3.1)$$

Or

$$\%\Delta D_t = \alpha(\%\Delta n_t) + \beta(\%\Delta i_t) + e_t^y(\%\Delta y_t) + e_t^p(\%\Delta p_t) \qquad (3.2)$$

Where:

$\%\Delta D_t$ = growth rate of electricity demand

$\alpha$ = population coefficient

$\%\Delta n_t$ = growth rate of population

$\beta$ = intensity coefficient

$\%\Delta i_t$ = growth rate of intensity of use

$e_t^y$ = income elasticity

$\%\Delta y_t$ = growth rate of per capita income

$e_t^p$ = price elasticity

$\%\Delta p_t$ = growth rate of price of elasticity

However, in this study, the effect on income in the community is not much significant and to use electricity from solar resources doesn't charge any tariff. Also there is low intensity of use as there is not so much change in structure of economic and social in the community. Hence, the assumption of this study is

$\%\Delta i_t = 0$

$\%\Delta y_t = 0$

$\%\Delta p_t = 0$

The equation to forecast the electricity consumption in rural area with various of photovoltaic systems is,

$$\%\Delta D_t = f(\%\Delta h_t)$$

Where;

$\%\Delta h_t$ = increasing of household in the community, this study assumed that 2.5% per year which higher than population growth rate in the Thai Government's 9[th] National Economic and Social Development Plan (NESDP) (Average of the country is 1% per year) Because of the people in rural may lack of birth control knowledge.

$\%\Delta D_t$ = growth rate of electricity demand of household in the community. So that to forecast the electricity consumption in each year is equal to

$$\%\Delta D_t = (\%\Delta h_t) \times \text{load consumption of household} \quad (3.3)$$

## 3.3 Economic Comparisons of Alternative Electrification Options

In determining a particular system for rural electrification, several options should be considered both from the technical and economical feasibility. From the technical point of view, there are the technologies to electrify any rural community depending on the available energy resources. However, there are limitations on what type of technology that can be used due to cost considerations.

This study gives an insight analysis of the various electrification options that can be considered for rural electrification, and their costs are analyzed based on their life-cycle. The type systems as well economic comparison were carried out to select the appropriate electrification option which can be more economically viable under local economic conditions. The different types of rural electrification options considered for this research includes the following with cross comparison with diesel generator system:

1. Solar Home System
2. Battery Charging Station
3. Centralized Mini-Grid System
4. Diesel Generator for Household Electrification

The analysis was done purely based on electricity uses within a specified period during the night time. It was assumed that the household uses imported or locally made lantern(s) for lighting purposes after electricity service has been shutdown. This makes comparison to be done on a relative level of footing. The following parameters were used for economic evaluation:

- The Capital Cost
- The Operation and Maintenance Cost
- The Life-Cycle Cost (LCC)

3.3.1 Capital Costs

These are the costs incurred during the purchase, transport, installation and commissioning of the various components of the electrification system at the start of the investment on the system. The sum of all the capital costs constitutes the Total Investment Cost of the system. In this analysis, the components considered for capital costs calculations are shown as below:

1) Solar PV module
2) Charge Controller/Inverter
3) Lead-Acid Battery
4) Diesel Generator
5) Plugs, sockets, switches, cables etc
6) Transportation and labor

3.3.2 Operation and Maintenance Cost

These are the costs incurred after the installation of the energy system for the operation and maintenance over its lifetime. It generally includes costs of fuel, lubricant, distilled water (for batteries), labor (for equipment servicing), recharging of batteries, spare parts etc.

3.3.3 Life Cycle Costs

This is the total cost of owning of system including its cost of acquisition, operation and maintenance and/or disposal. Its main objective is to choose the most cost effective approach from a series of different options in order to come up with the least long-term cost of ownership. In doing so, all future costs are discounted to their equivalent present day monetary value so that meaningful comparison can be made for investment appraisal. The following economic parameters were considered for the economic evaluation of the various options:

1) Period of analysis ($n$)- The lifetime of the longest-lived system under Comparison Economic Life – period of time over which an investment is considered to be the least-cost alternative for meeting a particular objective.

2) Inflation rate ($i$) – The rate of price increase of an item. For fuel, it is termed the fuel

3) Escalation rate ($e$) since it is normally different from the general inflation.

4) Discount rate ($d$) – This is the rate (relative to general inflation) at which the value of money will increase if invested.

In determining the Life-Cycle Cost, the following parameters are analysed for each electrification option in consideration:

1 Initial Investment Cost

2 Annual Recurring Operation and Maintenance Costs

3 Replacement cost of all equipments/component (taking into account inflation) in order to maintain system reliability.

4 The Salvage value of the energy system i.e. the cost of disposal or re-sale of the energy system at the end of its lifetime. For this analysis, it is considered to be negligible and hence neglected.

From the above values the $LCC$ can be obtained, which can then be divided by the Life Cycle Energy consumption in order to estimate the Life Cycle Unit Cost of Energy [$L_{COE}$].

Formulae for Life-Cycle Cost

These formulae are based on directives of International Energy Agency [IEA, 1991; p. 109-115]. For a diesel generator, the Life-Cycle Fuel Cost is given by:

$$Life-Cycle\ Fuel\ Cost = Annual\ Fuel\ Cost \times \sum_{t=1}^{n}\left(\frac{1+e}{1+d}\right)^{t} \qquad (3.4)$$

Where,

$e$ = Fuel inflation rate

$d$ = Discount rate

$n$ = Period of analysis (years)

$t$ = Year index

$$Life-Cycle\ Maintenance\ Cost = Annual\ Maintenance\ Cost \times \sum_{t=1}^{n}\left(\frac{1+i}{1+d}\right)^{t} \qquad (3.5)$$

Where,

$i$ = general inflation rate

$$Replacement\ Cost = \sum\left\{R_y \times \left(\frac{1+i}{1+d}\right)^{y}\right\} \qquad (3.6)$$

Where,

$R_y$ = Replacement cost of a system in year $y$ (for $y < n$), in year 0 Thai Baht

$y$ = Replacement year

Therefore, the Total life-cycle cost was obtained by summing all the life-cycle costs giving:

$$Total\ Life-Cycle\ Cost = I_O + LCC_{O\&M} + LCC_{RC} \qquad (3.7)$$

Where,

$I_O$ = Total initial investment

$LCC_{O\&M}$ = Life-Cycle Operation & Maintenance Costs

$LCC_{RC}$ = Life-Cycle Replacement Costs

But,

$$Total\ Life\ Cycle\ Energy\ Production = Annual\ Energy\ Production[kWh/Y] \times System\ Lifetime[y] \quad (3.8)$$

From the above equation, the Life Cycle Unit Cost of Energy [ $L_{COE}$ ] can be deduced, given by the equation:

$$L_{COE} = \frac{Total\ Life-Cycle\ Cost\ [THB]}{Total\ Life-Cycle\ Energy\ Production\ [kWh]} \quad (3.9)$$

3.4 Life-Cycle Cost of Solar Home System

In calculating the $LCC$ , all future costs were calculated taking inflation into account for each year concerned by applying the inflation factor $(1+i)^t$ . The total cost for each year was then discounted to the start year of investment using the discounting factor $(1+d)^{-t}$. The sum of all the present values gave the $LCC$ of the energy system concern. The analysis is based on a basic supply of electricity service for lighting and use of media devices as shown in the Load Demand. The cost estimates are based on cost of certain items in and around the locality. Where it cannot be obtained, cost estimates were taken based upon those supplied by PEA (see Annex). The salvage values of the SHS as well as other systems are assumed to be negligible and hence are not accounted for in this analysis.

Life-Cycle Terms of Reference

Period of Analysis ( $t$ ) = 20 Years

Discount Rate ( $d$ ) = 6.5 %

General Inflation Rate ( $i$ ) = 4.5 %

Fuel Escalation Rate ( $e$ ) = 5.5 %

Daily Energy Demand = 297.7 Wh

Life Cycle Energy Consumption = 20 x 365 x 297.7 = 2,171.75 kWh

Labor Cost = 5 % of Component Cost for replaced items

Capital Costs

Table 5 Capital Costs of SHS

| Component | Quantity/Capacity | Unit Cost (THB) | Total Cost (THB) |
|---|---|---|---|
| PV Module (Wp) | 120 Wp | 185 | 22,200 |
| Controller/Inverter | 150 W | 30 | 4,500 |
| Battery(>125 Ah) | 125 Ah | 20 | 2,500 |
| Installation Support | | | 1,500 |
| Transport & Labor | | | 1,500 |
| Lamps (10 W) | 2 | 40 | 80 |
| Switches (2) & Circuit Breaker | 1 Unit | 125 | 125 |
| Cabling (m) | 16 | 50 | 800 |
| Power Point Socket with switch | 1 | 150 | 150 |
| Lighting Fixtures | 2 | 85 | 170 |
| Acid (liters) | 9 | 24 | 216 |
| **Total Investment Cost** | | | 33,741 |

Operation & Maintenance Cost

Table 6 O&M Cost of SHS

| O & M Costs | Yearly Cost (THB) |
|---|---|
| Distilled water [3 l/yr at 12 Baht/l] | 36 |
| Maintenance Service (Estimated) | 200 |
| Total O&M cost | 236 |

Replacement of Balance of Systems Component

Table 7 Period of Replacement of Components of a SHS

| Component | Every (Year) |
|---|---|
| Charge Controller/Inverter | 10 |
| Battery (lead acid car battery) | 3 |
| Fluorescent Lamps & Ballast | 2 |

### 3.5 Life-Cycle Cost of Battery Charging Station

The method of analysis for this energy system is the same as that used for the SHS. Also the Life-Cycle Terms of Reference are exactly the same. The tables below give the different costs estimates.

Capital Costs

Table 8 Capital Costs of Battery Charging Station

| Component | Quantity/Capacity | Unit Cost (THB) | Total Cost (THB) |
|---|---|---|---|
| PV Module (Wp) | 120 Wp | 185 | 22,200 |
| Battery(>120 Ah) | 120 Ah | 20 | 2,400 |
| Lighting Fixtures | 2 | 85 | 170 |
| Lamps (10 W) | 2 | 40 | 80 |
| Switches (2) & Circuit Breaker | 1 Unit | 125 | 125 |
| Cabling (m) | 8 | 50 | 400 |
| Socket with switch | 1 | 150 | 150 |
| Modified Sine Wave Inverter | 150 | 30 | 4,500 |
| Installation & Transport | 1 | 1,000 | 1,000 |
| Acid (liters) | 9 | 24 | 216 |
| Total Investment Cost | | | 31,241 |

Operation & Maintenance Cost

Table 9 O&M of a Battery Charging Station

| Operation & Maintenance Costs | Quantity/ No. of Times | Unit Cost (THB) | Yearly Cost (THB) |
|---|---|---|---|
| Distilled water [l/yr] | 9 | 12 | 108 |
| Maintenance Service | 1 | 200 | 200 |
| Recharging Cost | 90 | 20 | 1,800 |
| Battery transportation | 90 | 10 | 900 |
| Operation & Maintenance Costs | | | 3,008 |

Replacement of Balance of Systems Component

Table 10 Period of Replacement of Components of a Battery Charging Station

| Replacement of BOS | Every (Year) |
|---|---|
| Inverter | 10 |
| Battery | 3 |
| Fluorescent Lamps & Ballast | 2 |

### 3.6 Life-Cycle Cost of Centralized Mini-Grid

The method of analysis for this energy system is the same as that used for the SHS. Also the Life-Cycle Terms of Reference are exactly the same. The tables below give the different costs estimates.

Capital Costs

Table 11 Capital Costs of Centralized Mini-Grid

| Component | Quantity/Capacity | Unit Cost (THB) | Total Cost (THB) |
|---|---|---|---|
| PV Module (W) | 2,300 | 185 | 425,500 |
| Battery | 200 kW | 400 | 80,000 |
| Lamps (10 W) | 12 | 40 | 480 |
| Switches (2) & Circuit Breaker | 7 Unit | 125 | 875 |
| Modified Sine Wave Inverter | kW | 20,000 | 20,000 |

Table 11 (Cont.)

| Component | Quantity/Capacity | Unit Cost (THB) | Total Cost (THB) |
|---|---|---|---|
| Installation & Transport | 1 | 25,000 | 25,000 |
| Instruction of Low voltage System | | | 17,6000 |
| Total Investment Cost | | | 727,855 |

Operation & Maintenance Cost

Table 12 O&M of a Centralized Mini-Grid

| Operation & Maintenance Costs | Quantity/ No. of Times | Unit Cost (THB) | Yearly Cost (THB) |
|---|---|---|---|
| Maintenance Service | 7 | 200 | 1400 |
| Operation & Maintenance Costs | | | 3439 |

Replacement of Balance of Systems Component

Table 13 Period of Replacement of Components of a Centralized Mini-Grid

| Replacement of BOS | Every (Year) |
|---|---|
| Inverter | 10 |
| Battery | 3 |
| Fluorescent Lamps & Ballast | 2 |

### 3.7 Life Cycle Cost of Using a Diesel Generator Electrification System

The analysis of the Life Cycle costing for using a diesel generator as a power source for supplying electricity was based on the use of a 2.8 kW, ETQ Diesel generator (Model: DG3LE) running for 4 hrs a day supplying a single household. It was assumed that regular and proper maintenance is carried out to ensure continuous and high quality delivery of electricity service within the specified timeframe.

Life-Cycle Terms of Reference

The terms of reference are the same as those of SHS except the following:

| Component | W | Running Hrs | Wh |
|---|---|---|---|
| Incandescent Bulbs | 75 | 4 | 300 |
| Incandescent Bulbs | 60 | 4 | 240 |
| Fluorescent lamp | 40 | 4 | 160 |
| TV | 75 | 4 | 300 |
| VCD | 25 | 2 | 50 |
| Fan | 30 | 4 | 120 |
| Total | 305 | | 1,170 |

Lifetime of the Diesel generator = 10 Years

Fuel consumption rate = 0.33 litters/kWh

Annual Energy Consumption = 427.05 kWh

Generator Annual Availability = 100%

Daily running hrs = 4 per day

Lube Oil sump capacity = 0.75 liters

Lube Oil Change [Every] = 250 hrs i.e. 6 times/year

Total Lube Oil Change/year = 4.38 liters

Monthly lube oil Consumption = 2 liters or 24 liters/year

Cost of 40W Ballast = 100 THB

Capital Costs

Table 14 Capital Cost of the Diesel Generator

| Capital Cost | Capacity/no. | Unit Cost (THB) | Total Cost (THB) |
|---|---|---|---|
| Generator (kW) | 2.8 | 11,285.71 | 31,599.99 |
| Switches | 5 | 30 | 150 |
| Labor (For Installation) | 1 | 2,000 | 2,000 |
| Power cable (m) | 8 | 100 | 800 |
| Electrical Plugs | 2 | 500 | 1,000 |
| Transportation | 1 | 500 | 500 |
| Power Transfer Switch | 1 | 400 | 400 |
| Fluorescent Lighting Fixtures | 1 | 100 | 100 |
| Incandescent Bulb (40W) | 3 | 30 | 90 |
| Incandescent Bulb (60W) | 1 | 35 | 35 |
| Cables(40m) & Wiring | 40 | 50 | 2,100 |
| Power Point Socket | 3 | 200 | 600 |
| Fluorescent Lamp(40W) | 1 | 60 | 60 |
| **Total Investment Cost** | | | 39,434.99 |

Operation Costs

This include the money spent in the purchase of diesel fuel and lubrication oil, but excluding salaries as the generator is used in the household for normal electricity supply.

Table 15 Operation Costs of a Diesel Generator System

| Operation Component | Quantity (l/yr) | Unit | Cost Yearly Cost (THB) |
|---|---|---|---|
| Annual Diesel Fuel oil Usage | 683.28 | 25 | 17,082.00 |
| Annual Lube Oil Usage | 28.38 | 80 | 2,270.40 |
| Total Operation Cost | | | 19,352.40 |

Maintenance Costs

Table 16 Maintenance Costs of a Diesel Generator System

| Component | Total Cost (THB) |
|---|---|
| Repair & Spares (5% of Generator Cost) | 1,580 |
| Labor (3% of Generator Cost) | 948 |
| Total Maintenance Costs | 2,528 |

Replacement of Balance of Systems Component

It should be noted that replacement of spare parts are all reflected in the total maintenance cost and as such only components that can be replaced by the user that are independent of the regular maintenance are included. The table below gives incite into that fact.

Table 17 Period & Costs of Replacement of Components of a Diesel Generator System

| Replacement of BOS | Every (Year) |
|---|---|
| Incandescent Bulb | 1 |
| Fluorescent Lamp | 2 |
| Replacement Cost of BOS | Total Cost (THB) |
| Incandescent Bulb (2 times in 1 yr) | 250 |
| Fluorescent Lamp & Ballast | 160 |

3.8 Economic Benefits of Using Photovoltaic Systems

The use of a SHS in a household, does not only bring a social change in the lives of the users, but may also reap some economic benefits through savings from avoided purchase of fossil fuels such as kerosene or diesel for the purpose of lighting. It can also contribute to the overall $CO_2$ abatement of the country which can be profitable, nationally, through Green House Gas Emissions Trading. These issues were analyzed to assess the extent to which such economic benefits can be obtained by adopting this technology.

Assumptions

Since a lot of the households are still using low efficient, locally made lamps that are normally fuelled by diesel oil, and others also use wick lamps with glass shade using kerosene, analysis was done for fuel savings and $CO_2$ abatement for both diesel and kerosene.

The calculations for $CO_2$ abatement are base on IPCC Guidelines for National Greenhouse Gas Inventories [IPCC NGGIP Publication, 2005; p. 1-40], as well as figures used in analysis were excerpted Green House Gas Emissions [Kaufman, S.L; 1999; p.11], in which the calculation method was carried out by Steven L. Kaufman.

Using Kerosene

No. of wick lamps = 2

Fuel oil consumption rate = 0.032 kg/ h

Estimated avoidance time per day = 4 hrs

Density of kerosene = 800 kg/m3 = 0.80 kg/l

Fuel oil consumption rate = 0.032 ÷ 0.80

≈ 0.04 l / h

Carbon content of Kerosene by weight = 85.9 % [Jungbluth, N; 1995; p.7 – 9]

Molecular weight of Carbon = 12

Molecular weight of Oxygen = 16

Conversion factor of Carbon to CO2 for wick lamps = 95%

Using Diesel

Density of diesel = 850 $kg/m^3$

= 0.85 kg/l

Carbon content of Diesel by weight = 87.4 % [Jungbluth, N; 1995; p. 7 – 9]

Fuel oil consumption rate =0.032 [kg/ h] ÷ 0.85 [kg/l]

≈ 0.038 l / h

CALCULATIONS

Using Kerosene

Total daily kerosene consumption = 2 × 4 × 0.04

≈0.32 litres per day per HH

Molecular weight of $CO_2$ = 44

Weight of $CO_2$ that can be produce by 1 molecular weight of carbon = 44 ÷ 12

≈3.67

Weight of Carbon in 1 liter of Kerosene = 0.8 [kg/l]× 0.859

≈ 0.69 kg/l

$CO_2$ emission factor for Kerosene = 3.67 × 0.69[kg/l]

≈ 2.52 kg/l

Annual avoided kerosene consumption per HH = 0.32 [l/d. HH] × 365 [d]

≈ 116.8 litres / HH

Avoided annual $CO_2$ emission from kerosene = 116.8 × 0.95 × 2.52

≈ 279.5896 kg of $CO_2$ / HH

Using Diesel

Total daily diesel consumption (l / d) = 2 × 4 [h/d] × 0.038 [l/h]

≈ 0.304 litres per day per HH

Annual avoided diesel consumption per HH = 0.304 [l/d. HH]× 365 [d]

≈ 109.9294 litres / HH

Weight of Carbon in 1 liter of diesel = 0.85 × 0.8747 = 0.74 kg

$CO_2$ emission factor for Diesel = 3.67 × 0.74 7 = 2.72 kg/l

Avoided diesel oil $CO_2$ emission = 2.72 × 109.9294

≈ 284.4719 kg of $CO_2$/HH

COST SAVINGS

Cost of Diesel = 25.00 THB

Annual savings from avoided diesel use = 25 THB × 116.8 litres / HH

= 2,748.24 THB / HH

Cost of Kerosene = 28.00 THB

Annual savings from avoided kerosene use = 28 THB × 109.9294 litres / HH

= 3,270.40 THB / HH

Discount Rate = 6.5%

Inflation Rate = 4.5%

The above cost savings were then analyzed over the life cycle of a SHS in order to estimate the total life cycle fuel cost savings discounted to the present time. These are shown in the Table 18.

Table 18 Life Cycle Avoided Fuel Cost

| Year | Inflated Present Value Factor | Annual Savings From Avoided Diesel Use | Annual Savings From Avoided Kerosene Use | Discount (6.5%) | Present Value of Diesel Savings | Present Value of Kerosene Savings |
|---|---|---|---|---|---|---|
| 1 | 1.04500 | 2,872 | 3,418 | 0.93897 | 2,697 | 3,209 |
| 2 | 1.09203 | 3,001 | 3,571 | 0.88166 | 2,646 | 3,149 |
| 3 | 1.14117 | 3,136 | 3,732 | 0.82785 | 2,596 | 3,090 |
| 4 | 1.19252 | 3,277 | 3,900 | 0.77732 | 2,548 | 3,032 |
| 5 | 1.24618 | 3,425 | 4,076 | 0.72988 | 2,500 | 2,975 |
| 6 | 1.30226 | 3,579 | 4,259 | 0.68533 | 2,453 | 2,919 |
| 7 | 1.36086 | 3,740 | 4,451 | 0.64351 | 2,407 | 2,864 |
| 8 | 1.42210 | 3,908 | 4,651 | 0.60423 | 2,361 | 2,810 |
| 9 | 1.48610 | 4,084 | 4,860 | 0.56735 | 2,317 | 2,757 |
| 10 | 1.55297 | 4,268 | 5,079 | 0.53273 | 2,274 | 2,706 |

Table 18 (Cont.)

| Year | **Inflated** Present Value Factor | **Annual Savings** From Avoided Diesel Use | **Annual Savings** From Avoided Kerosene Use | Discount (6.5%) | **Present** Value of Diesel Savings | **Present** Value of Kerosene Savings |
|---|---|---|---|---|---|---|
| 11 | 1.62285 | 4,460 | 5,307 | 0.50021 | 2,231 | 2,655 |
| 12 | 1.69588 | 4,661 | 5,546 | 0.46968 | 2,189 | 2,605 |
| 13 | 1.77220 | 4,870 | 5,796 | 0.44102 | 2,148 | 2,556 |
| 14 | 1.85194 | 5,090 | 6,057 | 0.41410 | 2108 | 2,508 |
| 15 | 1.93528 | 5,319 | 6,329 | 0.38883 | 2,068 | 2,461 |
| 16 | 2.02237 | 5,558 | 6,614 | 0.36510 | 2,029 | 2,415 |
| 17 | 2.11338 | 5,808 | 6,912 | 0.34281 | 1,991 | 2,369 |
| 18 | 2.20848 | 6,069 | 7,223 | 0.32189 | 1,954 | 2,325 |
| 19 | 2.30786 | 6,343 | 7,548 | 0.30224 | 1,917 | 2,281 |
| 20 | 2.41171 | 6,628 | 7,887 | 0.28380 | 1,881 | 2,238 |
| Total Life Cycle Fuel Savings Cost | | | | | 45,313 | 53,923 |

Another aspect of the benefit of adopting a SHS from the national perspective is the avoided $CO_2$ production from electricity generation, if these households were to have been supplied by grid electricity. In Thailand, the estimated annual Carbon Emission Factor for Thai Electricity Grid was 0.470 kg of $CO_2$/ kWh (2005) [Mitsubishi Securities,2003; p.3]; and considering the fact that the average estimated annual energy consumption for a rural household using SHS to be 2,172 kWh therefore,

Annual avoided $CO_2$ emission from grid electricity = 0.470 [kg of $CO_2$/ kWh] × 2,172 [kWh]

=1020.8 kg of $CO_2$ per year per household

### 3.9 Case Study: Ban Pean Village , Doi Saket District, Chiang Mai Province

This village is located in Thep Sadeth Sub-District, Doi Saket District of Chiang Mai Province. It is about 15 km from the district head quarter and 8 km from the main highway. The nearest grid extension is 3 km away from the village; however, getting access to the village is a daunting task. The village is located on a hilltop with winding roads (most of which is very narrow and unpaved) going uphill and downhill in an ascending manner before it can be reached. It has 12 households and one Buddhist temple, with a total population of 30 people. The village is highly forested and the houses are about 10 to 15 m apart with a lot of surrounding trees.

Figure 7 Road to Ban Pean - viewed from uphill

3.9.1 Solar Home System in Ban Pean

The SHS in Ban Pean was installed in 1997 by the Department of Alternative Energy Development & Efficiency (DEDE) as part of a pilot project for rural electrification of remote villages using Solar PV. It was funded by the Royal Project, which was created by the Thai Royal Family. Each household was given a SHS; however, only eight (8) are now being used. This was due to the fact that four (4) households have moved out of the village to nearby towns. The system was designed for use with the following components:

1) One (1) 75Wp Mono-Crystalline Solar PV module
2) One (1) 10A Solartron Charge Controller
3) One (1) 100/120 Ah car battery
4) Two (2) 18W fluorescent lamps
5) Two (2) lighting switches and one socket outlet for a TV

All the PV modules were mounted on a 3m high metal pole with guy wires - preventing it from swaying during strong winds- at about 18° south. The system was purely design for DC operation.

The following figure shows the author interviewing the village head in Ban Pean village:

Figure 8 Author interviewing the head of village in Ban Pean village in Chiang Mai

3.9.2 Management of the Solar Home Systems in Ban Pean

The SHS installed by DEDP is currently being overseen by a Regional Project Office of the Royal Project. When the systems were installed in 1997, basic site training was given to each household head- who were generally men- on the operation and maintenance of the system. This includes checking and maintaining battery water level as well as regular cleaning of the PV module and energy saving measures for optimization of system performance. The household heads are then responsible for training the other members of their households on these issues. Each SHS belongs to the household and they are responsible for the maintenance of their system. However, they are not allowed to expand their system at its current configuration. The management structure is shown in Figure 10. Whenever there is a problem with any of the component of the SHS, the user informs the village head who will then give him contact details of the Officer in Charge at the Royal Project Office.

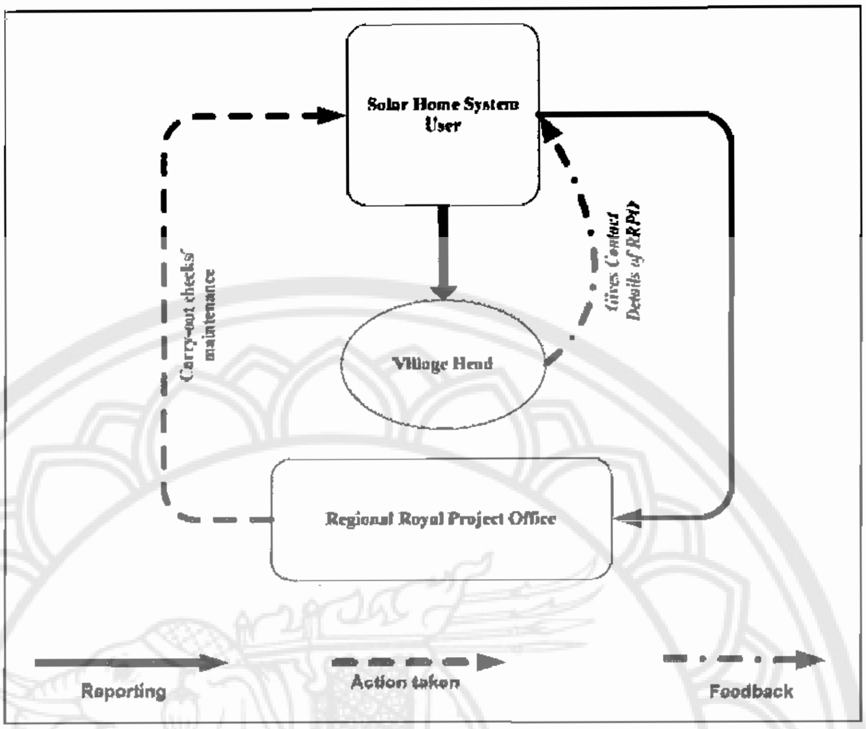


Figure 9 Management Structures of the SHS in Ban Pean

The Regional Royal Project Office (RRPO) has a team of trained technicians- trained by DEDE- who will then go to the village to carry-out the necessary repairs when the situation permits. All expenses with respect to spares are borne by the user [Interview with Village Head and a Royal Project Officer on 17/12/2005].