CHAPTER II

REVIEW OF RELATED RESEARCH AND LITERATURE

2.1 Solar Energy Potential in Thailand

Thailand is blessed with its global positioning at high solar insolation zone, i.e. close to the equator; there is almost always a constant exposure of Thailand to the radiation from the sun during sunrise and sunset throughout the year. The solar map of Thailand is shown in figure 2. The average solar insolation in Thailand is about 5 kWh/m^2.day, which is 923.58 × 10^6 GWh/year when multiplied by the land area of Thailand. In 2003, the energy demand of Thailand was 65,520,396 GWh, and it is just 7 % of the available solar energy potential in the country. However, the current area available for the exploitation of solar energy is 5.6×10^9 m^2 [SERT, 2005], making the available solar energy being 10,220 × 10^3 GWh, which is 15.6 % of the energy total demand of the country in year 2003.

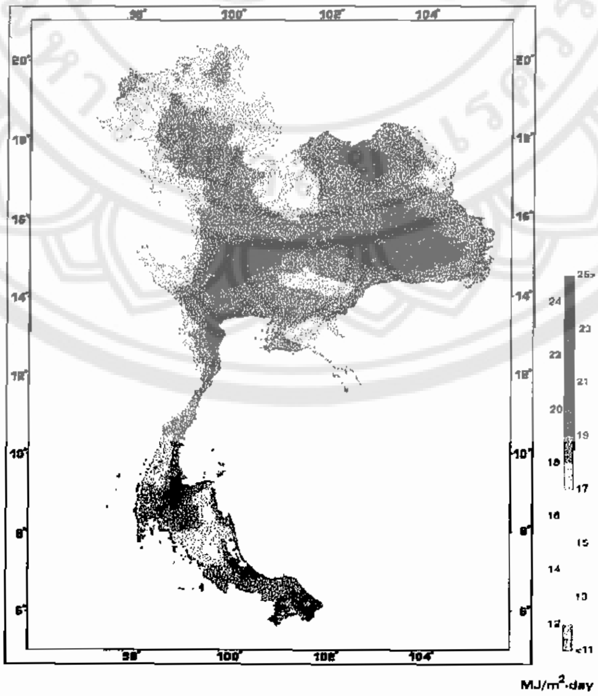

Figure 2 Solar Map of Thailand (Source: DEDE)

About 5.5 MWp Solar PV systems for stand-alone and grid connected applications have been reported. Most of them (95%) are in remote areas and are off-grid, such as solar PV battery charging stations and PV pumping for village water supply [Amatayakul et al, 2003, p.11].

2.2 Rural Electrification in Thailand and other countries

Thailand's Provincial Electricity Authority (PEA), the country's only dedicated rural electricity utility supplier, has successfully electrified 98.9% of rural Thai villages. The remaining 750 villages are considered to be too remote to electrify with grid extensions. For these villages, the PEA has been focusing on the use of stand-alone electricity generation systems – either diesel generators or renewable energy systems that harvest local flows of wind, sun, and waterfall. The Thai Government's Energy Policy and Planning Office (EPPO) has levied tax on the sale of fossil fuels in the country, creating a substantial fund for energy conservation and renewable energy. The PEA's "20-islands project" will involve the use of this fund to build renewable energy systems for 20 of Thailand's unelectrified island communities. The project will be implemented based on surveys and interviews with inhabitants of the 20-islands villages, participant observation of PEA engineers and through interviews of decision-makers.

"Research and Photovoltaic Application in Thailand and Trend in The Future" [Kiratikara, 1998] reported that the main photovoltaic applications in Thailand are in PV water pumping, PV battery charging, PV standalone and grid-connected systems. Most of the researches were carried out the studies of the systems and only minor studies were carried out on materials for producing solar cells. According to the National Economic and Social Development Plan of Thailand, photovoltaic applications and usage are expected to become widespread in the future. The market will be changed from market of government sector (providing subsidies) to consumer based market.

"Evaluation of Photovoltaic Systems in Thailand" [Rakwichian, 1999] studied the efficiency, potential, characteristics, as well as the social and economic impact of PV systems in Thailand. From the research, it was found that the total capacity of PV systems installed in Thailand is about 4.4 MW_p in late 1999. The testing results also showed that the efficiencies of the pumping system and battery charging system found to be 5.7% and 1.3% respectively. In addition, the study reported that although the costs of PV systems are high at presently, the price is expected to decrease relatively in the future. The study indicated that it is very beneficial to use such free energy from the sun with no environmental impact. Although PV systems are suitable for using in remote areas, there are basic problems, which need to be resolved concerning system management and maintenance. To promote PV system applications, it is necessary to set up an organization, which is solely responsible for training the users and system management after installation in order to enjoy the full benefits of both economic and social aspects.

"Best Practices for Photovoltaic Household Electrification Programs: Lessons from Experiences in Selected Countries" [Anil Cabraal, Mac Cosgrove-Davies, Loretta Schaeffer, 1996], A recent World Bank review of rural electrification experiences in Asia recognized the potentially useful role of solar home systems. "Since rural electrification programs can easily overextend themselves, project appraisal needs to focus more attention on identifying the economic limits of extensions to the grid and on the economic potential of alternative energy sources, particularly solar energy". PV projects should be appropriately integrated into the rural electrification planning process as a least-cost electrification option. From the users' perspective, electricity's perspective, rational economic policy dictates a least-cost path to energy service delivery. The rural electricity planner needs to know how to select the least-cost approach for delivering energy services at an acceptable level of reliability and quality from among the off-grid options for power supply, including solar home systems; kerosene generators and batteries; and a grid-based power supply.

"Commercial Photovoltaic Electrification in Botswana" [Midas M. Sekgabo, 2000], Prior to 1997, commercial electrification in Botswana had been undertaken by the Botswana Power Corporation (BPC). The Department of Electrical and Mechanical Services (DEMS) has the function to provide power by stand-alone diesel generator sets and centralized power supply systems in rural areas to cater for Government institutions, where grid power is not economically viable to connect. This set-up left a vacuum as to the provision of power on a commercial basis to areas that are far from the grid and sparsely populated. To address this problem the Government of Botswana introduced the National Photovoltaic Rural Electrification Program (NPVREP) in March 1997. This came after the evaluation of the Manyana Photovoltaic Pilot Project conducted by the Renewable Energy For African Development (REFAD), which recommended replication of the project in other villages on a commercial basis. A follow-up study to assess `ability and willingness to pay' for solar lighting systems was being conducted in 1996 at Manyana, Takatokwane and Molepolole. The findings of this study were positive, indicating that there is a demand for at least 237 installations in the three villages. Subsequently it was decided that the program be implemented nation-wide instead of being limited to only the three villages.

2.3 Energy and Economic Evaluation Method

"PV energy in the THERMIE programme" [B Yordi, 2000], Fundamental research and technological development on PV devices and components reminds vitally important to develop lower cost PV modules with higher efficiencies and longer lifetime. However, it is equally important to move forward with the demonstration of PV energy services in the competitive energy markets of both the EU and developing countries. Further work based on the environmental integration of PV in urban and rural areas remains important, as do further demonstrations of sustainable schemes for supplying and financing PV energy services.

"Experimental Optimization of the Performance and Reliability of Stand-Alone Photovoltaics Systems" [D. L. King, T. D. Hund, W. E. Boyson, and J. A. Kratochvil, 2002], disclosed that Stand-alone photovoltaic systems are deceptively complex. Optimizing the performance and reliability of these systems requires a complete understanding of their behavior as a function of site-dependent environmental conditions. Individual component specifications provide useful design information. However, to fully understand the interactions between components, it is necessary to simultaneously characterize the performance of the system and its components under actual operating conditions. The paper describes how a new 30-day outdoor testing procedure was coupled with our array performance model to accomplish this objective. The procedure determines battery capacity and appropriate set- points for charging, and based on daily intervals quantifies dc-energy available from the array, charge-controller efficiency, battery efficiency, inverter efficiency, system efficiency, days of autonomy, and ac-energy available by month.

The ISES, in co-operation with the Fraunhofer ISE [ISES, 2001] have released the survey on "Rural Energy Supply Models - RESuM". The result is a guideline for government, business entrepreneur, and financing organizations to providing energy to rural areas using renewable. The study collated and summarized information on the set-up of different dissemination methods as well as experiences made with them. The central question is: "How to get the product to the end user?" with special consideration of the business level – the level of interaction between the system or service provider and the customer. The product could either be an energy supply system for auto-generation, such as a pico-hydro system, or a service, such as electricity.

A characterization of the rural energy supply model was developed based on the existing experiences, consulted experts, and additional information generated through the consideration of practical examples. Regarded aspects include the contract between the system or service provider and the customer and project or business entrepreneur, like promotion and installation. The knowledge about indispensable requirements and certain obstacles to the dissemination models for rural energy supply permits to avoid mistakes in future actives and give preference to promising strategies – adapted to the special conditions. Advantages and key barriers referring to the organization process of the different rural energy supply models were worked out. In addition, a catalogue of critical success factors within the models was developed to help the key players overcome model-specific problems. The study results in a structured presentation of different energy supply models, their characteristics, advantages and disadvantages, supported by project examples.

Reaching the rural customer, various ways exist for bringing the energy supply system or the service to the rural customer. The flow chart below gives an overview of the main categories and models – the Rural Energy Supply Models. This categorization is the result of the approach taken by ISES and Fraunhofer ISE.

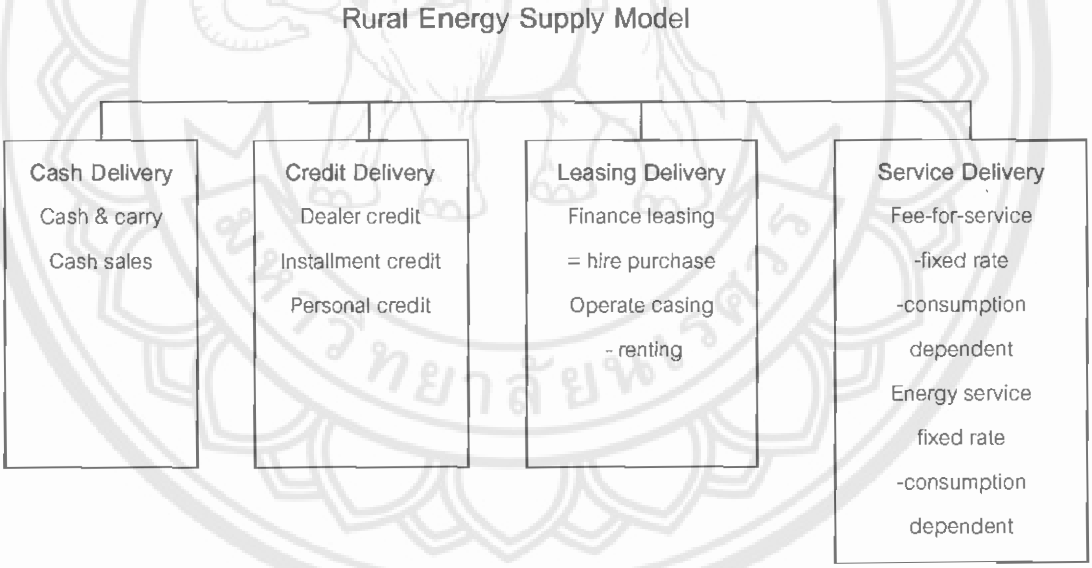

Figure 3 Rural Energy Supply Model

Some of these rural energy supply models have a higher practical relevance than others, and as a result of the practical examples considered, it was found that in the rural energy sector, often a mixture of these models were used.

“Economic Evaluation of End-use Energy Technologies” [ECONorthwest, 2001] performed an economic evaluation of the market potential for a broad range of advanced end-use energy technologies. The analysis combined economic screening with a more detailed linear programming model to determine the optimal mix of each technology under different regional market growth scenarios. The analyses illustrated how variations in regional heating and cooling demand, as well as the price of electricity, are the principal drivers of the market for new end-use technologies. The results were used to guide EPRI R&D funding allocation decisions.

“Economic Evaluation of Energy Storage Technologies” [ECONorthwest, 2001] the Electric Power Research Institute, ECONorthwest staff evaluated the economic potential of alternative energy storage technologies for electric utility applications. Developed a linear programming model to determine the optimal mix of generation and storage technologies, based on anticipated system demand patterns, existing generation mix and the economics of alternative technologies. Using this decision framework, assessed the potential benefits of storage technologies under varying assumptions about future demand and technology costs. Benefits assessments were used to guide allocation of R&D funding for storage technologies at EPRI.

Energy - Economic Development Impact Model [Glen Weisbrod, 2001] analyzing the economic consequences of energy programs and policies. It estimates the magnitude of impacts on regional business growth over time, resulting from changes in energy prices and/or changes in investments in power generation and transmission facilities. It is applicable to assess impacts of alternative generation technologies, demand management programs and deregulation policies. The model provides a means for estimating the current pattern of spending on energy facilities & technologies, the allocation of spending benefits to area businesses, the allocation of costs to customers (for regulated activities) or to firms (for deregulated activities), impacts on the cost competitiveness of all types of local business activities and the long-term effects on economic growth of the affected area. The model provides a means for estimating the potential direct and indirect economic impacts on a state, county, community or service area. It can be used alone or in conjunction with a regional input-output or economic simulation model. capital and operations spending program for new power plants: coal, natural gas, biomass, wind, other; annual costs for energy services and demand-side management services; financing and allocation of long-term capital costs and short-term operating costs; differences in relative prices associated with differential loads; customer sizes & types (SIC group). Model Output impacts on the relative cost competitiveness of customers impacts on business revenues, output, employment and income in the affected area: by business type; short-term and long-term differences in impacts. Applications include: state policy impact and benefit-cost studies utility pricing and targeting studies. Energy Regional Impact Assessment (ERIA) has been applied in various forms for studies of energy programs and policies in Iowa, Wisconsin, and California.

The "Project Economic Evaluation Model (PEEM)" software [Strand Management Solutions, Inc. and DHL Associates, 2000] was developed in the mid-1990's and modified in later years, delivers an economic evaluation that can be understood and applied by all participants in the decision-making process. For example, in deciding whether to replace a hydroelectric unit's generator cooling system, PEEM would weigh options in bringing the pump to the required performance level. Would it be best to replace, redesign, or rebuild the existing system? Should the current system be "band-aided" as a temporary solution? What is the net present value and cost of each option, the internal rate of return, and the payback period? How is the decision affected by the planned life of the entire generating unit? Once a decision to proceed with a project has been made, full documentation of the process that led to the decisions is available in the software. The PEEM software also provides for comparing the results of an evaluation of a specific capital improvement with any number of other proposed projects. This feature allows managers to rank capital projects within departments or within the full utility or corporation.

At the Institute of Economic Research (IER) in Ljubljana a two-sector model was developed (Kuzmin et al., 1995). This model distinguishes between the energy sector and the others sectors of the economy. It is based on a model called MACRO that has been built at IIASA, Luxemburg, Austria. The model MACRO contains a constant elasticity of substitution (CES) production function which separates energy input and the input of labor and capital. The primary factors are included as a Cobb-Douglas production function. The main purpose of the model developed at the IER is the calculation of price elasticities for energy. The model contains a production function, an investment equation, equations determining the demand for labor and capital, and public and private consumption. Also include are exports of good and services, as well as taxes, transfers to the population, and identities.

SEEM: The Slovenian Macro Economic Energy Model [Klaus Weyerstrab, Hubert Reisinger, Norbert Wohlgemuth, 1998] was developed a governmental strategy for supporting the Slovenian economy and the rational use of energy in order to achieve a maximum of welfare. This is restricted by regulations on emissions and with certain strategies by EU regulations and a minimum amount of domestic coal to be consumed. Criteria for evaluating the investigated governmental strategies include gross domestic product, household income, sector value added, rate of unemployment, rate of inflation, current account of balance of payment, effects on the general government budget, emissions of SO_2 , NO_x dust and CO_2 , primary energy consumption and the total costs of the energy system.

In order to show the effect of Integrated Resource Planning (IRP) strategies and to optimize these strategies not only with respect to the development of the energy system but also with respect to the development of the economy as a whole, the planning system developed in IRP- Slovenian has to be complemented by SMEEM, as well as a model which improves the “market valuation” of the goods and services produced in Slovenia, and a model for the market penetration of energy efficient technologies. Figure shows the outline of the whole modeling sequence.

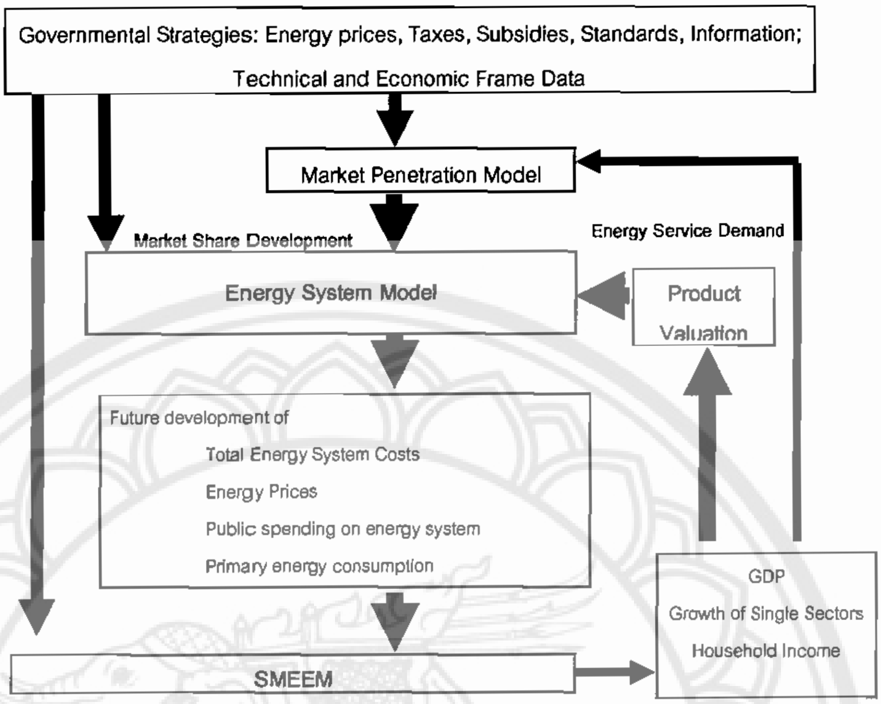

Figure 4 Energy System Model, Slovenian Macro Economic Energy Model (SMEEM) and other models necessary for a closed loop energy-economy investigation.

In principal the two main models can operate independently. But to show the effect of governmental strategies on the energy system and the economy the results of one model are to be considered in the other model. The link between the models is that the output of one model is considered when defining the input of the other model. There is no hard link between the two models.

2.4 Photovoltaic System VS. Grid-Based Power Supply

Grid-based power supply and PV systems are not necessarily mutually exclusive options in delivering electricity services to rural areas. Rural electrification planners should take advantage of multiple options at their disposal. Grid-based power is the least cost option for large concentrations of household or productive loads. It offers substantial economies of scale, owing to the large fixed-cost investment in distribution lines and generation facilities. However, grid solutions require a minimum threshold level of electricity demand and certain load densities to achieve these economies of scale.

Deciding whether the grid or solar PV is the least-cost option for supplying electricity to rural areas requires attention to:

— ***Household service level:*** the daily energy consumption of the average household to be served, expressed as the number of hours of task and area lighting and the watt-hours required to operate appliances;

— ***Total number of households to be served:*** the number of households to be served, multiplied by average daily household consumption;

— ***Load density:*** as indicated by the number of households to be served per unit service area (in km^2) or by the number of households to be served per unit of distribution line (that is, per km of low-voltage (LV) distribution line);

— ***Productive loads:*** the number and power requirements of productive loads such as rice mills, grain-grinding mills, water pumping, and commercial or service sector loads; and

— ***Load growth:*** the annual increase in the load that will result from increases in both the number of customers served and the demand for energy.

Figure 5 identifies the "break-even" thresholds for grid-based and solar home systems for Indonesian communities with up to 1,000 households and household densities ranging from 50-150 households per km^2. The break-even point at which grid-based power supply and PV systems are equally cost-effective in this assessment depends on the size and density of the specific load to be served as well as the distance from low- (LV) and medium- (MV) voltage lines.

The analysis assumes that households receive equivalent levels of service from both PV and grid-based arrangements corresponding to 6 hours of task lighting, 8 hours of area lighting, and 60 Wh of other loads per day. Three scenarios are presented for villages located at varying distances from the existing grid:

Case 1: a remote area where the grid option is to construct an isolated grid powered by a diesel or a small hydroelectric plant;

Case 2: a village located 5 km from an MV substation or line; and

Case 3: a village located 3 km (the typical maximum distance for LV line extension) from an LV line.

The break-even curve in each graph traces the line along which the levelized costs are the same for either PV household systems or grid-based power, given specific combinations of load (household connections) and load density (household connections per km2). PV electrification is the least-cost option below the line and grid-supply is the least-cost option above the line. For example, in Case 1, an isolated diesel-powered grid is the least-cost option for a village with 400 household connections and 100 households per km^2. If this village had half the number of household connections and a lower household connection density (for instance, 65/km^2), PV household systems would be the least-cost choice. (The analysis in Figure 5 is based on grid service and PV systems cost data for Indonesia.)

Case 1 highlights an economic niche for PV home systems in small, sparsely settled, isolated communities. Here, solar homes systems are less expensive than either kerosene and batteries or grid-based power. This is true for villages of widely varying sizes and household densities. Typically, PV household systems are the least-cost option for villages with fewer than 200 connections.

Case 2 highlights a second economic niche for solar home systems: in communities near (5 km or less) an existing MV line, PV systems are the least-cost option, if few households are to be served. Typically, PV household systems are the least-cost option for villages up to 5 km from the grid but with fewer than 100 connections.

Case 3 defines a third economic niche for PV service in villages located near an LV line (3 km). Grid extension is normally the least-cost option for such settlements. However, PV systems are the least-cost option, even in Case 3, if fewer than 50 households are to be connected. Often, these sparsely settled communities are passed over in the rural electrification process and remain unelectrified pockets locked inside electrified regions.

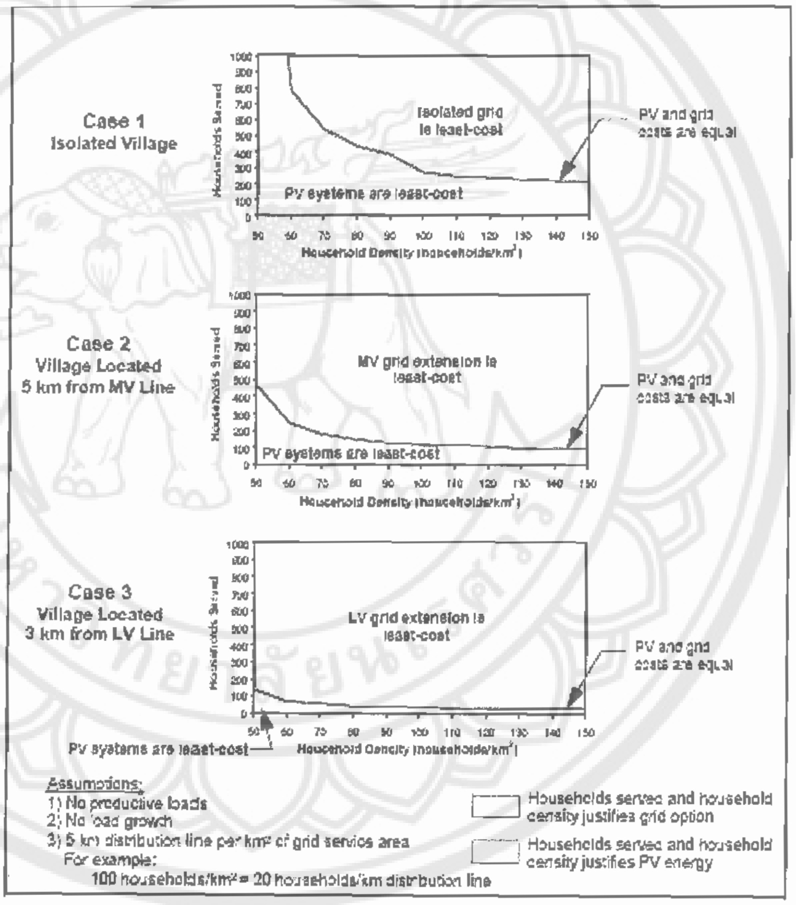

Figure 5 Indonesia: Break-Even Thresholds for PV- and Grid-Based Electricity Supply, by Village Location

2.5 Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a comparison of the estimated costs of an action with the estimated benefits it is likely or intended to produce. It is controversial when applied to policies intended to address potentially harmful or fatal risks, particularly environmental risks. Many critics argue that one cannot place a dollar value on human life. But that is not the intention. Rather, cost-benefit analysis permits comparison of various options, all of which may be beneficial but not all of which can be undertaken simultaneously. Researchers who study risks refer to "life-years saved," based on statistical probabilities.

2.5.1 Cost Benefit Analysis Involves a Particular Study Area

The impacts of a project are defined for a particular study area, be it a city, region, state, nation or the world. In the above example concerning cotton the impact of the project might be zero for the nation but still be a positive amount for Arizona. The nature of the study area is usually specified by the organization sponsoring the analysis. Many effects of a project may "net out" over one study area but not over a smaller one. The specification of the study area may be arbitrary but it may significantly affect the conclusions of the analysis.

2.5.2 Decision Criteria for Projects

If the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile. This is equivalent to the condition that the net benefit must be positive. Another equivalent condition is that the ratio of the present value of the benefits to the present value of the costs must be greater than one.

If there are more than one mutually exclusive project that have positive net present value then there has to be further analysis. From the set of mutually exclusive project the one that should be selected is the one with the highest net present value.

If the funds required carrying out all of the projects with positive net present value are less than the funds available this means the discount rate used in computing the present values is too low and does not reflect the true cost of capital. The present values must be recomputed using a higher discount rate. It may take some trial and error to find a discount rate such that the funds required for the projects with a positive net present value is no more than the funds available. Sometimes as an alternative to this procedure people try to select the best projects on the basis of some measure of goodness such as the internal rate of return or the benefit/cost ratio. This is not valid for several reasons.

The magnitude of the ratio of benefits to costs is to a degree arbitrary because some costs such as operating costs may be deducted from benefits and thus not be included in the cost figure. This may be done for some projects and not for others. This manipulation of the benefits and costs will not affect the net benefits and it will not raise the benefit cost ratio which is less than one to above one.

By reducing the positive and negative impacts of a project to their equivalent money value Cost-Benefit Analysis determines whether on balance the project is worthwhile. The equivalent money value are based upon information derived from consumer and producer market choices; i.e., the demand and supply schedules for the goods and services affected by the project. Care must be taken to properly allow for such things as inflation. When all this has been considered a worthwhile project is one for which the discounted value of the benefits exceeds the discounted value of the costs; i.e., the net benefits are positive. This is equivalent to the benefit/cost ratio being greater than one and the internal rate of return being greater than the cost of capital.

Life Cycle Cost (LCC) is the total discounted (present worth) cash for an investment with future costs during its economic life.

$$LCC = CC + \sum C_n/(1+r)^n - SV/(1+r)^t \tag{2.1}$$

Where:

CC = initial capital cost (capital, labor, overhead)

C_n = operating cost (O&M, fuel, tax and interest) in year *n*

SV = Salvage Value (in year t)

Energy Use

$$Energy\ use = \sum_{i=1}^{i=n} Q_i . I_i \qquad (2.2)$$

Where:

Q_i = quantity of energy service i

I_i = intensity of energy use for energy service I (in kW, MWh/m^2-year)

Quantity of Energy Services

$$Q_i = N_i . P_i . M_i \qquad (2.3)$$

Where:

Q_i = quantity of energy service i

N_i = number of customers or units in a facility eligible for end-use i

P_i = penetration (% of units or customers) of end-use service I (can be > 100%)

M_i = magnitude or extent of use of end-use service I (hours/yr, m_2, etc.)

Specific definitions of N , P ,and M are flexible and depend on end-use and sector.

Q reflects "non technical" aspects of energy demand, unlike i, which is related to the send-use technologies.

Simple payback (SPB) is the time required for the sum of the cash flows from the annual savings to cover the initial cost (without discounting). This is an indicator of liquidity and risk.

The discount rate measures the time-value of money exclusive of inflation. The real (inflation-corrected) discount rate (r) is :

$$SPB = \frac{CC}{D} = \frac{Capital\ Cost}{Annual\ Savings} \tag{2.4}$$

$$(1+r)(1+f) = 1 + r_n$$
$$r_n = r + f.r + f$$
$$r = (r_n - f)/(1+f)$$

Where:

n = number of years
f = annual inflation rate

Internal Rate of Return (IRR) is the discount rate (r) at which net present worth of present and future cash flows (NPW) equals zero.

$$P = 0 = \sum F_n/(1+r)^n \tag{2.5}$$

Where P , F_n are known, solve (by iteration) for IRR, or use function @ IRR.
For uniform annual savings (D) over n years resulting from a present capital expenditure CC:

$$P = 0 = CC - \frac{D}{CRF_n, irr} \quad or \quad CRF_n, irr = \frac{D}{CC} \tag{2.6}$$

Where: $$CRF = \frac{r}{[1-(1+r)^{-t}]}$$

Capital Recovery Factor (CRF) is the ratio between uniform annual savings and the present value of the cash flow stream. This is the minimum value of savings which makes the investment cost effective.

The estimated cost of per kilowatt hour (kWh) of electricity generated by PV (P_{PV}) can be calculated by the equation:

$$P_{PV} = \frac{IC_{PV} \,.\, CRF(r,dt)}{Q_{sol} \,.\, R \,.\, PF \,.\, \eta_{PV} \,.\, A_{sp}} \tag{2.7}$$

Where:

IC_{PV} = the investment costs (Baht per kWh)

CRF = capital recovery factor

Q_{sol} = yearly solar insolation per m^2

R = the ratio of total radiation on the optimum tilted plane to that of the horizontal surface R

PF = the performance factor

η_{PV} = the efficiency of the PV system

A_{sp} = the specific area needed per kWp installed (total PV area)

2.6 Optimal Renewable Energy Model

Optimal Renewable Energy Model that minimizes the cost/efficiency ratio and determines the optimum allocation of different renewable energy systems for various end-uses. The potential of renewable energy sources, energy demand, reliability of renewable energy systems and their acceptance level will determine the pattern of renewable energy systems and are used as constraints in the model.

The model allocates the solar energy distribution pattern in India, which would be helpful for policy makers in commercializing the renewable energy sources to the greatest extent.

A study was study conducted to identify the critical factors in renewable energy utilization in the Indian context. The study revealed that cost and efficiency are highly critical factors in the utilization of renewable energy sources, and those factors such as technology, availability and reliability should be considered in order to select the appropriate photovoltaic systems for difference end-uses. For optimization, the cost/efficiency ratio was chosen as the objective function and minimization of the function was carried out. The ultimate aim was to select systems with low cost and high efficiency. The following are the unit costs of energy used in the optimization model. The costs renewable energy systems were estimated. The different efficiencies of renewable energy systems substituted in the model are show in the model.

The energy demand was predicted by using the two-stage least square forecasting method. The energy demand for different end-uses was determined by comparing it against the social acceptance level and was used as demand constraint in the OREM. Even though the potential sources of renewable resources are abundant in India, factors such as the quality of the resources, intermittent nature, and technical feasibility would determine the amount of renewable energy to be used. In the OREM, these factors are considered potential constraints. A failure analysis was done to find out the reliability factor of photovoltaic systems and the factor was taken as reliability constraint in the OREM for reliable power supply. The calculated reliability index for photovoltaic systems was used to formulate the reliability constraint equation.

The mathematical representation of the OREM is given in the following equations:

Minimize $$\sum_{j=1}^{6}\sum_{i=1}^{I}(C_{ij}/\eta_{ij})X_{ij} \qquad (2.8)$$

Subject to

Social acceptance
$$\sum_{j=1}^{6}\left[\sum_{i=1}^{l}(X_{ij}/S_{ij}) \le D_j\right. \qquad (2.9)$$

Demand
$$\sum_{j=1}^{6}\left[\sum_{i=1}^{l}(X_{ij}) \le D_j\right. \qquad (2.10)$$

Potential limit
$$\sum_{k=1}^{6}\left[\sum_{i=1}^{m}(X_{ik}) \le P_k\right. \qquad (2.11)$$

Reliability
$$\sum_{k=1}^{3}\left[(1/R_k)\sum_{i=1}^{m}(X_{ik}) \le P_k\right. \qquad (2.12)$$

Where

C = unit cost of the system
η = efficiency of the system
X = quantum of renewable energy
D = energy demand
S = social acceptance level
P = potential
i = renewable energy system
j = end-use
k = resource
l = number of systems in respective end-use
m = number of systems in respective resource

The model has been sun for the renewable energy distribution in India for the year 2020 for different end-uses.