Renewable Energy for Rural Electrification in Thailand: A Case Study of Solar PV Rooftop Project

Wichit Krueasuk, Pornrapeepat Bhasaputra, Woraratana Pattaraprakorn, and Supattana Nirukkanaporn

Abstract— *Rural electrification (RE) is still remained to be a challenge for Thailand due to its sparse electricity demand in the remote areas. Expansion of the electricity transmission and distribution service to such area is difficult and uneconomic. The use of renewable energy technologies not only offers an environmental friendly and economically viable for RE, but also aligns with the National Agenda to promote the use of renewable as alternative energy resources to reduce the dependency of imported fuel and increase fuel diversification. The Thai government is targeting 25% of the energy generation from renewable energy resources by the year 2021. The government has established and implemented several projects to promote the use of renewable energy, especially solar PV systems. This paper proposes an analysis of the problems encountered during the progress of this RE program, with the use of data obtained from Provincial Electricity Authority (PEA). The analysis takes into account of the uncertainty of PV generation and investment conditions. Under economic analysis, the levelized cost of electricity (LCOE) method is used to evaluate the designed system with a comprehensive way to find the LCOE optimized of RE in Thailand. The results provide a positive support to government investment in subsidy program for the implementation of solar PV system for RE.*

Keywords— **Rural Electrification, Renewable Energy, PV, LCOE.**

1. INTRODUCTION

The Eleventh National Economic and Social Development Plan (NESDP: 2012-2016) of Thailand [1] has main objectives to reduce poverty and tackle inequality. Its timeline is shown in Fig.1. The infrastructure is solution for the development benefits of solving the problem of structural injustice. The NESDP targeted establish to reduce the income gap of the population and reduce inequality in access to the basic social services and the economic opportunities. It also aims to provide sufficient infrastructure as well as electrical system to cover the populated areas of the country. In particular, rural electrification is a service to raise the quality of life, income distribution and economic diversification in disperse areas.

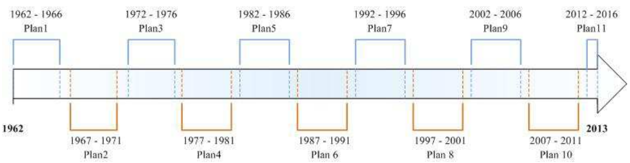

Fig.1. Timeline of NESDP

The Fifth NESDP in 1982-1986, emphasized the development of the efficiency power supply and the energy conservation, consequently the government have policy for subsidy the energy source from renewable energy. The NESD planning has the preparation to support the renewable energy in a sustainable way to reduce pollution and the energy imports.

Electricity supply development is considered to be an in economic investment in the remote areas or the scattered demand areas for the utility supply industries. In the past, RE have utilized diesel generators to supply electricity the consumption of diesel oil as fuel has resulted in expensive generation cost, which brought the per unit generation cost of electricity in remote areas. Therefore, renewable energy such as solar power, wind power and hydro-power provides solution for RE system in Thailand.

Incessantly, the renewable energy is supported by Thai government accord the Power Development Plan 2010-2030 Rev.3: PDP2010 [2] and Renewable Energy Development Plan: REDP2008-2022[3]. REDP have targeting development of renew energy for about 12 % in 10 years, the new Renewable and Alternative Energy Development Plan: AEDP 2012-2021[4] is aiming for an incremental of 25 % in 15 years. The power generation from renewable energy technologies is promoted by the “Adder” and “Feed-in Tariff (FIT)” measures. Presently, the Solar PV Rooftop is emphatic for the power generation from the solar PV with total capacity purchase is 200 MW. The government subsidy for the project is the FIT for the medium-large and factory businesses, the small businesses and household in the rate are 6.96 Baht/kWh, 6.55 Baht/kWh and 6.16 Baht/kWh respectively for 25 years [5]. The population near the grid benefits both from the subsidy and system stability while the rural area population does not. The promotion government has created social inequality with regard to the accessibility to electricity and benefits from renewable energy subsidized program; hence,

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opportunities in the management of solar PV system for RE should be provided for rural population.

The appropriate time for investments of solar PV is presented by LCOE method, considering different scenario for PV sizes, sun hour and discount rate. The analysis incorporates various parameters corresponding to economic investment and the society solution for RE. The paper is structured as follows. Section 2 presents conceptual background about the rural electrification, renewable energy and solar PV project in Thailand. Section 3 defines the analytical model of LCOE of a technology as the sum of generation costs and integration costs per generation unit of that technology. Section 4 expands the solution method, followed by results and discussion in section 5. Section 6 summarizes and concludes.

2. BACKGROUND

2.1 Rural Electrification in Thailand

Electrification vated vary significantly across countries in the Asia and the Pacific (Table 1) . Typically, South and Southeast Asian countries are characterized by high and high density populations with about 59.2% and 37.8%, respectively, of their total populations not yet having access to electricity [6].

Table 1 Electrification access rate in Asia and the Pacific

Region					
South Asia		Southeast Asia		East Asia Pacific	
Country	%	Country	%	Country	%
Sri Lanka	62	Singapore	100	Marshal Island	100
Pakistan	52.9	Thailand	98.5	China	98.6
India	43	Malaysia	96.9	Tonga	85
Bangladesh	32.5	Philippines	87.4	Fiji	80
Nepal	15.4	Vietnam	75.8	Palau	60
		Indonesia	53.4	Papua New Guinea	46
		Cambodia	15.8	Micronesia	45
		Myanmar	5	Kiribath	40
		Laos	NA	Vanuatu	26
				Timor-Leste	22
				Solomon Islands	15

Low power energy consumption of the household Thai villages in rural area, especially the electric energy consumption. Most people in rural are poor and the cooking consume the wood gathered from the surroundings for charcoal production, the kerosene wick lamps and candles are used for lighting at night. They need electricity for just in case very basic essential needs such as use TV and radio and using electricity for just a few hours at night. Usually, the households have 4 to 5 people with 5 to 10 houses of small villages and 50 to 100 houses of large village in Thai villages rural. Moreover, many villages are difficult to the travel enter the distance about 5 km to 40 km, especially in mountainous regions or the island.

The rural electrification (RE) program in Thailand was implemented through Provincial Electricity Authority (PEA), which is responsible for electricity distribution in provinces as Provincial Electricity Organization (PEO) was established in 1954. PEO is the responsibility to generate and distribute electricity to all areas in Thailand except the Bangkok metropolitan areas, it was renamed PEA in 1960. The Metropolitan Electricity Authority (MEA) was responsible for distribution in the Bangkok Metropolitan Area. In 1969 the Electricity Generating Authority of Thailand (EGAT) was established, EGAT consolidate different organizations that generating electricity to meet the growing electricity demand, with mandate for generation and transmission system. EGAT, PEA and MEA are state enterprises with responsibilities were limited to the distribution of electricity in their respective jurisdictions. In 1992, Independent power producers (IPPs) were allowed to generate electricity sell to EGAT. EGAT continues to be the sole agency responsible for transmission.

PEA initiate the rural electrification program in 1977 based on the 25-year "National Plan for Accelerated Rural Electrification"[7]. The long-term plan was divided into 5- year plans to relate the 5-year national economic and social development plans (NESDP) of the country. Each plan set specific targets for increasing electricity access in rural areas[8]. Office of Rural Electrification (ORE) was established by PEA for planning and implementing the RE programmer. In Thailand, rural electrification efforts during the 1960s were through use of decentralized diesel-generating plants. The growth of electrification was relatively low during this period and only 7% of the rural households had access to electricity in early 1970s. In 1978, a year after initiation of the RE program, only 19% of the total households had access to electricity. By 1984 this percentage had increased to around 43% and by 1986 to 86% and by 1990 electrification level was more than 91%. Fig.2 shows the electrification level in Thailand. By the year 2000 percentage of household having access to electricity in rural and urban areas differed by a very small percentage show in Fig. 2.

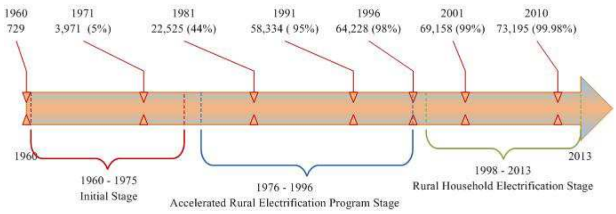


Fig.2. Electrification Level in Thailand

Initial Stage: During 1964-1975, PEA implemented 3 RE Projects by the supply from small diesel power plants to about 10,000 villages and able to achieve 20 % RE. Accelerated Rural Electrification Program Stage: During 1976-1996, the implementation was through a connected to grid system after PEA implemented the accelerated RE Program, the number of Electrification Village increase as follow: 1981: 22,525 Villages (44%), 1986: 41,374 Villages (75%), 1991: 58,334 Villages (95%), 1996: 64,228 Villages (98%).

According to PEA Report in 2012, within 74 provinces under its responsible areas in Thailand, there are a total of 73,363 villages those had access to electricity, which is equivalent to 99.98% of the total number of villages in country. These covered 99.10% of the total households in the country, which is equal to 16,212,750 households who had access to electricity. However the number of population is growing every year.

2.2 Renewable energy of rural electrification in Thailand

The results study [9] makes a modest attempt, based on extensive literature review, to highlight the rural electrification situation at the regional and country level in South Asia. The significant achievement shows that all the government policy is based on an a priori judgment that renewable energy should be reserved for marginal areas where grid extension is a challenge and so governments are not attempting distributed generation to enhance access utilizing the locally available resources in grid connected areas. Furthermore, based on sustainable development with emphasis on environmental consideration, the feasibility of electrification by using different types of renewable energy such as solar, biomass, hydro, wind and tidal have been studied. Renewable energy is the most promising option for feasible and sustainable decentralized rural electrification generation systems, particularly in rural areas with massive renewable energy resources [6, 10]. Despite reliability of grid connection, results indicate that renewable energy sources are the best choice especially in areas far from grid connections. Challenges between financial institutes and executive agencies result in resource management and technology development in order to overcome existing barriers and issues[11].

Thai government's goal of 25 % renewable energy production by 2021 is an attempt to reduce national dependence on non-domestic energy sources as well as reduction of the environmental burdens associated with domestic energy production[3]. The renewable energy subsidy is very important, Feed in tariffs of USA and Europe are studied to be applies in Thailand[12]. After, NESDP established, PEA's the programme on design, implementation and evaluation for pilot hybrid renewable energy systems for electrification of remote villages. The methodologies used in systems design descriptions and operations of the system was presented in [13]. The technology roadmap of the renewable energy industry was proposed to emphasize the importance[14].In addition, the economic analysis, the capital cost, net present cost, cost of energy and CO_2 emissions were determined for different types of system configuration [15, 16]. Several models of renewable energy resources was proposed by considering daily operation profile[17] and the impact of renewable energy. These models used as a guideline for strategic planning and long-term preparation [18] . The study on the security of primary energy supply for electricity generation in the next 20 years is providing of National Power Development Plan of Thailand (PDP 2010)[19].

2.3 PV Projects in Thailand

The global PV supply chain has rebounded strongly from the overcapacity-induced lows of 2011 to 2013, with robust demand growth from markets such as China, Japan and the U.S. coming into contact with a fitter, leaner supply chain. Tightest PV market supply is expected in 2014 in nearly half a decade, supply constraints and rising input costs are expected to result in meaningful increases in pricing across the PV value chain [20].

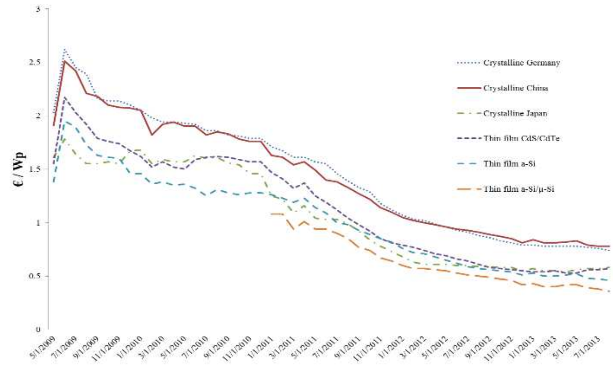


Fig.4 Global PV Pricing Outlook: Q3 2014

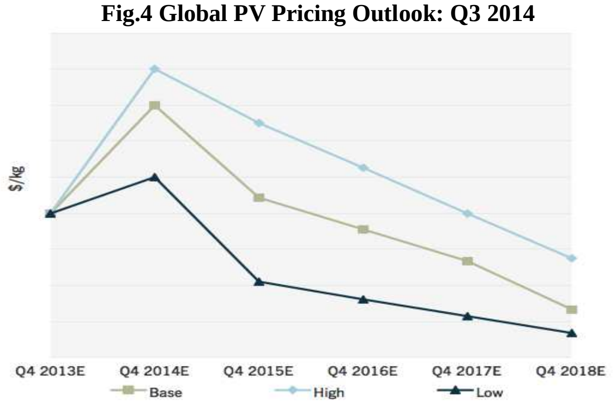


Fig.5 Industry Average Polysilicon Price

The Energy providing that Policy and Planning Office (EPPO) had the survey data, the average prices of solar panels PVX for all the technologies have declined from 1.14 USDW in December 2011 to 0.84 USDW in October 2012 (or 26 percent). While the cost of Solar PV Balance of System (BOS) ago, still does not change those results. Thus the total costs of the project to produce electricity from solar energy reduce from 70.4 million baht per MW. According to the Energy Research Institute proposed the reduction cost of 60 million baht per MW (or about 15 percent). In 2013 the system costs continued to decline by another 7-8 percent, which would make the total cost of system is approximately 55 million baht per MW.

Solar PV technologies serve as a potential supplemental electricity source in Thailand to sell electricity to the grid. Single-crystalline panels have a higher efficiency compared to amorphous silicon and thin-film solar panels, which have a lower cost. The study attempts to reconcile the environmental and economic differences between single-crystalline and thin-film photovoltaic technologies to assist policymakers in the formulation of GHG mitigation strategies [5] . Furthermore, Solar PV systems will be the first priority for renewable energy technology used. Some households many use additional agricultural diesel for generating electricity in case of energy supply from battery or Solar PV system does not meet energy demand according to the survey results in the rural villages [21].

3 BASIS OF THE ANALYTICAL MODEL

3.1 The Levelized Cost of Energy formula for solar electricity costs

Levelized Cost of Energy (LCOE) are a common metric for comparing power generating technologies. There was criticism particularly towards evaluating variable renewables lie wind and solar PV power based on LCOE because it ignored variability and integration costs [22]. LCOE can be taken of as the price at which energy must be sold to break even over the lifetime of the technology. It yields a net present value in terms of, bath per kilowatt-hour. This is an assessment of the economic lifetime energy cost and lifetime energy production (Eq.1) and it is applicant for any energy technology. In order to compute the financial costs, the equations can be embellished to take into account not only system costs, but also other factors such as financing, insurance, maintenance, and different types of depreciation schedules.

The model calculates the cost of solar electricity during the whole lifetime of the systems, whilst other models estimate that cost annually[23]. The life-cycle technique was applied to estimate the LCOE, the expenses and sales revenues those occur in future time discounted to present time value of money by using discounted cash flow (DCF) techniques, i.e., by calculating the present value of the cash flows by means of a discount rate, r. In this context, the LCOE is determined when the present value of the sum of the discounted revenues is equivalent to the discounted value of the sum of the costs during the economic lifetime of the system, N years, i.e. ,

$$\sum_{n=0}^{N} \frac{Revenues_n}{(1+r)^n} = \sum_{n=0}^{N} \frac{Costs_n}{(1+r)^n} \quad (1)$$

Thus, the Net Present Value (summation of the present values PV of the cash flows), NPV, of the project is zero, i.e.,

$$NPV = \sum_{n=0}^{N} PV = 0 \quad (2)$$

Therefore the LCOE is the averge electricity price needed for Net Present Value (NPV) of zero when performing a discounted cash flow (DCF) analysis, so that an investor would break even and so receive a return proportional to the discount rate of the investment. The sum of the present values of $LCOE_n$ multiplied by the energy generated annually, E_n should be equal to the sum of the present values of the costs of the project, i.e.,

$$\sum_{n=0}^{N} \frac{(LCOE_n)x(E_n)}{(1+r)^n} = \sum_{n=0}^{N} \frac{Costs_n}{(1+r)^n} \quad (3)$$

Assuming a constant annual value for the LCOE, we can write:

$$LCOE = \sum_{n=0}^{N} \left(\frac{Costs_n}{(1+r)^n}\right) / \sum_{n=0}^{N} \frac{E_n}{(1+r)^n} \quad (4)$$

Note that (Eq.4) is an arithmetic result of rearranging (Eq.3) for energy discount. Hence, according to (Eq.4), the LCOE equals to the sum of all the discounted costs incurred during the lifetime of the project divided by the units of discounted energy produced. It should be noted that the summation calculation starts from *n*=0 to include the initial cost of the project at the beginning of the first year, which should not be discounted. Therefore, the initial cost can be included outside the summation and the summation is started from *n*=1 both in the numerator and in the denominator, i.e.,

$$LCOE = \left(Initial\ Costs + \sum_{n=0}^{N} \left(\frac{Annual\ Costs_n}{(1+r)^n}\right)\right) / \sum_{n=0}^{N} \frac{E_n}{(1+r)^n} \quad (5)$$

Finally, the net costs will include cash outflows like the initial investment (via equity or debt financing), interest payments if debt financed, operation and maintenance costs (note: there are no fuel costs for solar PV) and cash inflow such as government incentives as shown in (Eq.6). As such, the net cost term can be modified for financing, taxation and incentives as an extension of the initial definition. If LCOE is used to compare to grid prices, it must include all costs required (including transmission and connection fees if applicable) and must be dynamic with future projects acknowledged in the sensitivity analysis. In this paper, no incentives will be considered [24, 25] .

$$LCOE = \frac{\sum_{n=0}^{N} \frac{IC_n + FOM_n + VOM_n}{(1+r)^n}}{\sum_{n=0}^{N} \frac{E_n}{(1+r)^n}} = \frac{\sum_{n=0}^{N} \frac{IC_n + FOM_n + VOM_n}{(1+r)^n}}{\sum_{n=0}^{N} \frac{S_n(1-d)^n}{(1+r)^n}} \quad (6)$$

where, r = discount rate (%); d = degradation rate (%); n = specified period (year);FOM_n = fixed O&M cost per year (Baht);VOM_n=variable O&M cost per year (Baht);S_n = energy output per year (kWh).

4. SOLUTION METHOD

The energy consumption data of the rural electrification disposition is analyzed by the simulation from the PEA. This paper assigned the average energy unit between 45-112 kwh/month and the PV sizes have 300 w- 750 w of the household. Various prescribed data is the corresponding of the rural electrification in rural area. The sun hour of the PV generation per day is 5 hour/day which is mean value hour in Thailand. There scenarios high, base and low PV investment cost were simulated using global price as parameter as shown in Fig 5. The simulated PV costs show in the Fig.6. The PV costs of which the package price is 100 Baht/Watt are show in Fig. 7 included cost of installation and battery but exclude inverter.

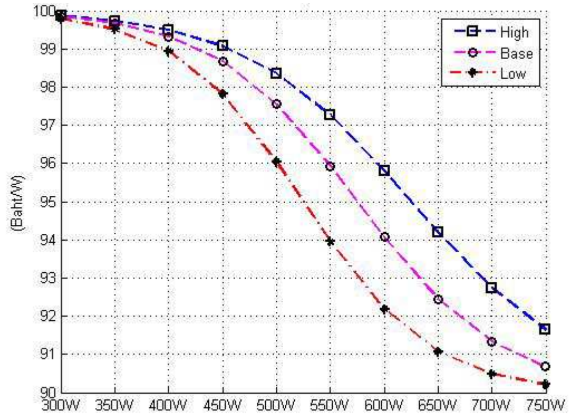


Fig.6 Function Cost PV per watt installed

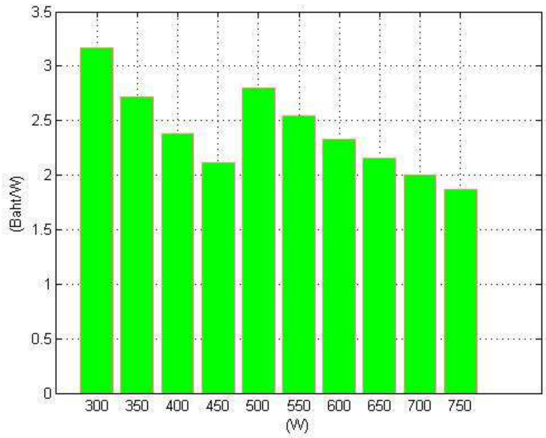


Fig.7 Cost PV inverters per watt installed

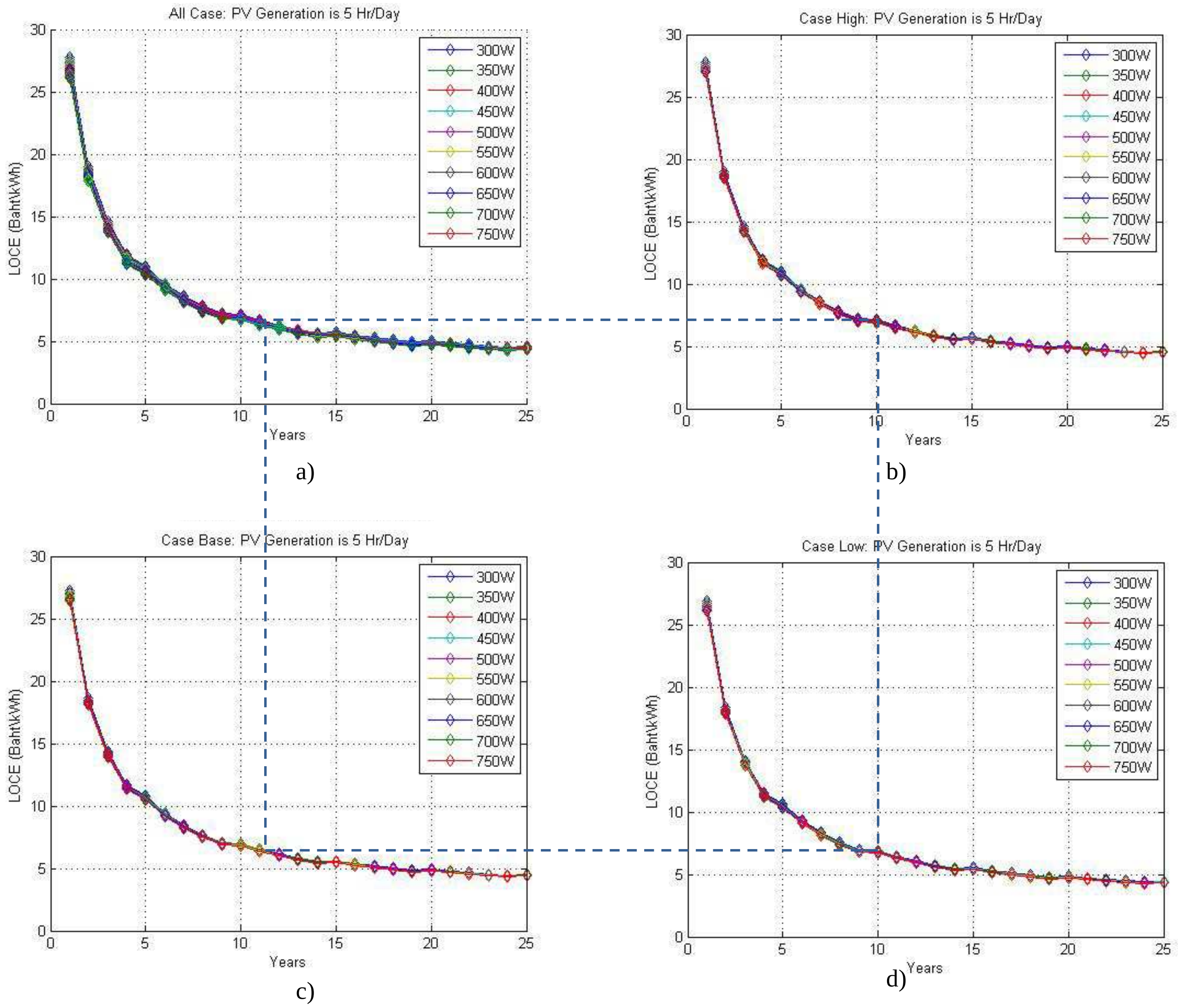


Fig.8 (a) All Case: PV Generation is 5 Hr/Day (b) Case High: PV Generation is 5 Hr/Day(c) Case Base: PV Generation is 5 Hr/Day(d) Case Low: PV Generation is 5 Hr/Day

The parameters simulated for LCOE analysis consisted 1% for the operation and maintenance cost and the inverter and other replacement with expect to the initial cost with the investment carried out every 5 year.

5. RESULTS AND DISCUSSION

The analysis of the PV project (10 years) has the condition that the pv can generate average power of 5 hr/day of year (mean in Thailand). An Analysis of the project is carried out for 10 years, primarily due to speculation that the project may have problems on other side during this period. The results were shown in Table.2 with the LCOE does not obviously change, but it will result in most of the investments and the life of the project show in the Fig.8.

Table 2. LCOE (5 Hr/Day,Project 10 year)

	High	Base	Low
300W	7.122	6.9964	6.8967
350W	7.074	6.9483	6.8486
400W	7.0379	6.9123	6.8126
450W	7.0099	6.8843	6.7846
500W	6.9875	6.8619	6.7622
550W	6.9692	6.8436	6.7439
600W	6.9539	6.8283	6.7286
650W	6.941	6.8153	6.7156
700W	6.9299	6.8043	6.7046
750W	6.9203	6.7947	6.695

However, the results showed that the factors change LCOE is directly related to the age of the equipment or the life project i.e., the longer life, the lower LCOE value (as shown in Fig.9, Fig.10 and Fig.11, for three scenarios, respectively. While investment equal intervals will be valid for the same but the rates of change of the LCOE not be observed between the life project of 15- 20 years compared 20-25 years, the result that it can be compared to the increase in base tariff of 3.5 Baht / kwh with an annual increase of 3%, with a reduction of the LCOE each year by 0.5%, then we know of suitable for investment

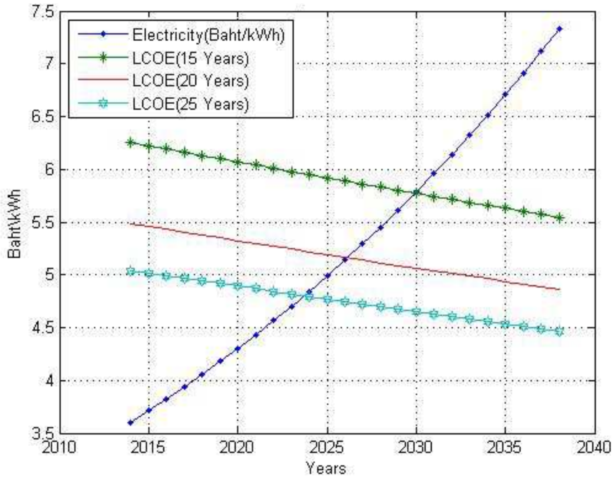


Fig.9. Case High: 500w, 4.6hr/Day.

The analysis to be consistent with the investment currently analyzed to evaluate LCOE in the project 20 years, considering the case different conditions justify the cost of the system has decreased dramatically (Case High), normal price (Case Base) and decreased slowly (Case Low) same as the average cost in the region has decreased by more than 10% of the price in the system. Conclusions are presented in Fig.12, which is divided in two by a conclusion as (a), (c) and (e) shows the results of the LCOE of the PV generation per day, a different part (b), (d) and (f) the effect of the conditions to the investment results of to changes discount rate.

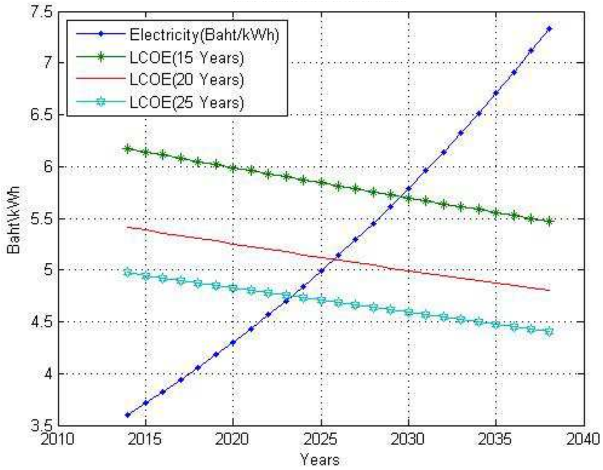


Fig.10 Case Base: 500w,4.6hr/Day.

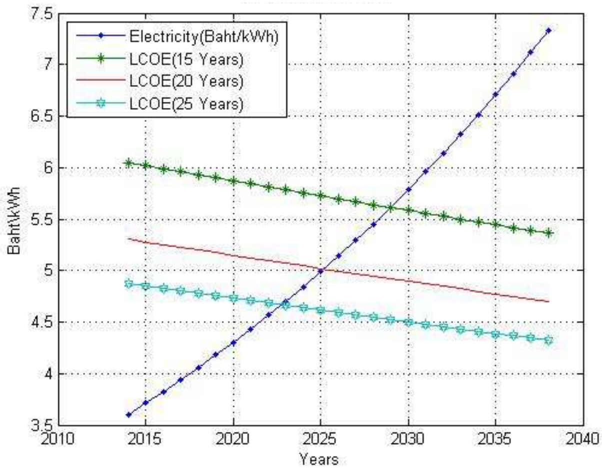
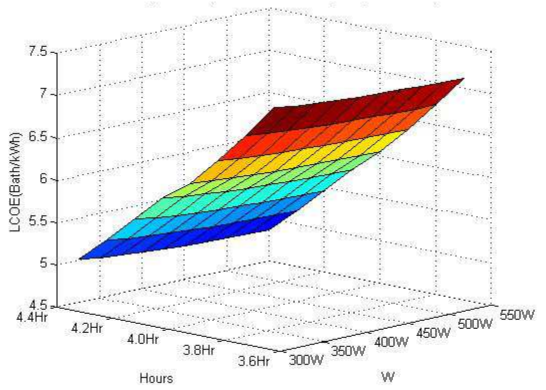


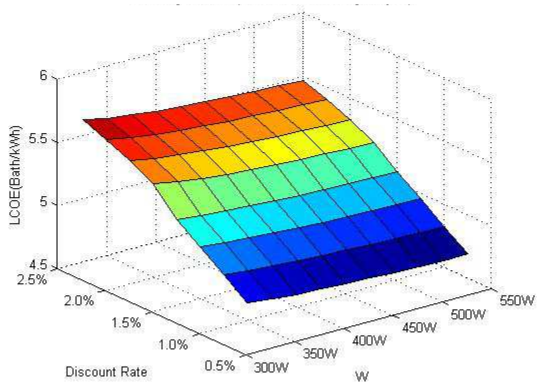
Fig.11 Case Low: 500w,4.6hr/Day

The result of the change in the average hours of electricity per day (considering 3.6 hr / day to 5 hr / day) that the LCOE changes from 5 Baht/kWh to less than 7.5 Baht/kWh and the change of interest rate (the 0.5% to 4%) that the LCOE are the range of 5.7 Baht/kWh to less than 4.6 Baht/kWh overall than in the past, which consider to be the LCOE are much reduced.

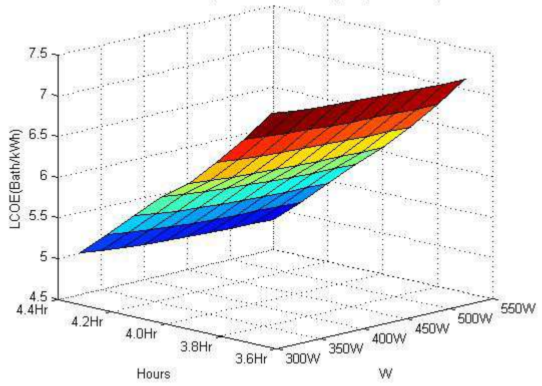
The results of the calculations were presented. Under the economic outlook for investment, the authors incorporate the consideration of the current cost of solar cells and the proper average level for rural communities in remote areas. For 25 years investment under the fastest price variation (Case High), the reduction of 10% per annum for PV system investment of 100 Baht/watt and 0.5% increase of base tariff of 3 Baht/kWh could be found. The appropriate year for the investment size of PV household as 500 watt and the PV generate per day is 4.6 hour/day as shown in Fig.10.The appropriate year for investment in the year 2024 that the base tariff and LCOE as 4.84 and 4.80, respectively. It is also noted that for early investment than 2024, it will create over opposite investment but if the investments was made slowly to the investment opportunities too.



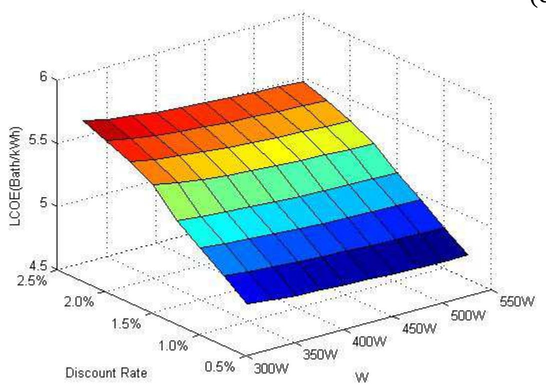
(a)



(b)



(c)



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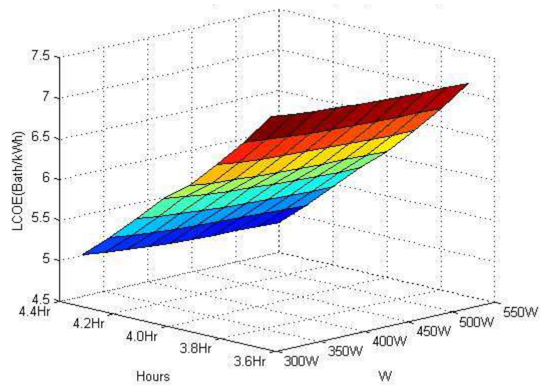

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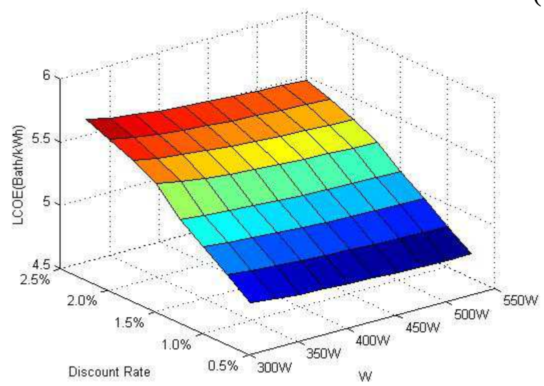

(f)

Fig. 12. (a) Case High: LCOE of PV Generation changes; (b) Case High: LCOE of Discount Rate changes; (c) Case Base: LCOE of PV Generation changes (d) Case Base: LCOE of Discount Rate changes; (e) Case Base: LCOE of PV Generation changes; (f) Case Base: LCOE of Discount Rate changes.

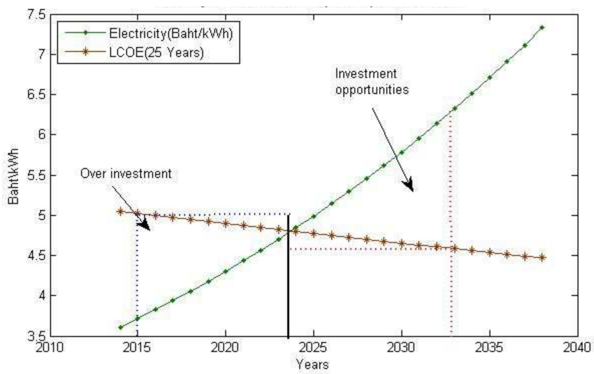

Fig. 13. Case High: LCOE of PV Generation (25 years\500w\4.6Hr).

6. CONCLUSION

In Thailand, the government will make an investment currently invest for RE from PV panels. Both the economy and society needs to be considered. For the economics, dimension real cost of PV systems and if analysis base on reasonable time period there is carried out will not be over-investment and investment opportunities. However, a complete infrastructure in the community to contribute to the economic development in remote communities, causes substantial growth in the overall development of the country and most importantly the conflict in society will be less.

Presently, Thailand has encouraged households with electricity generation from the PV panels as the solar rooftop project, The government will purchase on the feed-in-tariff price and the life have 25 years ,can be connected to the grid system of MEA and PEA. At the same time communities in remote rural areas of the country are not the beneficiaries of the project.

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