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**Article**

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# An Evaluation of Economic Potential Solar Photovoltaic Farm in Thailand: Case study of Polycrystalline Silicon and Amorphous Silicon Thin Film

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## ABSTRACT

Solar energy in Thailand plays an important role to achieve the target of the alternative energy development plan (AEDP). Enormous investments from investors are expected to occur for support AEDP. Therefore, the objective of this study was to evaluate and compare the economic potential of solar photovoltaic (PV) farm between polycrystalline silicon (PCSS) and amorphous silicon thin film (ASTF) type. Questionnaires submitted to private solar PV farm for collecting data. As a result, four main investment costs of PSS are identified: (1) photovoltaic module; (2) connection system; (3) inverter, and (4) engineering construction, distributed as 58.09%, 19.66%, 12.96%, and 4.47%, respectively. The financial analysis found that payback period, internal rate of return, and solar plant capital of ASTF were less than PCSS; however, it returns low income along 25 years than PCSS. It could be suggested that the investment on PCSS is worth than ASTF.

**Keywords:** Economic Potential, Solar Photovoltaic Farm, Investment, Financial Economic
**JEL Classifications:** C8, G0, M2

## 1. INTRODUCTION

Nowadays, the importance of exploring renewable energy has dramatically increased. Increasing global population leads to more energy demand, while limited resources for energy supply. The International Energy Agency (IEA) has reported that developing countries will double their energy need in response to their growth by 2020 (IEA, 2008). Solar energy can convert to electric by using a photovoltaic (PV) device. With this device, the electricity produced from solar energy has less impact on the environment; furthermore, it has also secure, clean, and suitable (Shukla et al., 2018). Solar energy can provide many advantages on the environment, leading to worldwide attention on solar energy to support the critical need for energy usage. Therefore, the trend of installing solar system has highly continued growth around the world.

Likewise, Thailand has been very active in bringing solar energy to use, although the current situation of Thailand's electricity production is heavily dependent on fossil fuels, especially natural gas (69.22%) and coal (19.10%) (Usapein and Chavalparit, 2017). Energy resources in Thailand has been reduced, opposite with the energy demand in the country. In 2016, Thailand has imported energy with totaled value of 1.42 trillion baht, the highest value was come from crude oil (1.07 trillion baht), followed by natural gas, and liquefied natural gas, respectively (MoE, 2016). To reduce dependence on foreign energy imports, Thailand is urgently needed to encourage using more renewable energy. Therefore, the alternative energy development plan (AEDP) has established by Ministry of Energy to promote renewable energy consumption. In addition, the latest version of Thailand power development plan (PDP) has adjusted and increased the share of renewable energy to be at least 20% by 2025 (Ketjoy and Mansiri, 2013; MoE, 2011; Suthiwongwong, 2011). If this plan success, the electricity generation capacity from renewable energy will go up to 14,000 MW by 2021. With the expected electricity generation capacity from solar energy in AEDP (3,000 MW), solar energy will play an important role on the target of AEDP (EGAT, 2016).

According to the AEDP, it is expected that there will be huge investments in solar energy technology to support such plans. However, one of important problems is that most of the new Thai investment owners have lacked the knowledge about returns on their investment. Some projects have a risky investment due to the insufficient understanding of the nature of the renewable energy business. Some investors have a solar license from Thai government, but they are not knowledgeable or experienced on solar energy business (Rinphol, 2016; Suwanasang and Tongsopit, 2015; Tantisttayakul, 2015). In addition, the research paper related with the investment on solar PV farm in Thailand is very rare. Therefore, the objective of this study was to analyze and evaluate the economic potential of solar PV farm in Thailand along with primary and secondary data collection. The detail on cost of construction and operation will be evaluated and can be used as a guideline for researchers, policy maker, and consultants for proposing the new ideas of developing solar investments in the future.

### 1.1. Status of Solar PV Farm in Thailand

The solar PV farm in Thailand is becoming greater along with Electricity Regulator Commission (ERC) license system for the registration of solar PV farm. This is because Thai government has created the program by adding the prices of purchase electricity produced by solar cell for very small power producer (VSPP) (Hachigami, 2015; Jäger-Waldau, 2012; Sahay et al., 2013). Solar PV farm in Thailand have been increased exponentially both in number of stations and capacity for year 2009–2016, except in the year 2014, as shown in Figure 1.

Although there had previously been a solar investment project supported by Thailand's government, the payback period (PB) took a long time. However, the increased financial knowledge on the types of solar PV farm, the amount of money needed to set up an investment fund, the length of time for the PB, the percentage of internal rate of return (IRR), the performance ratio and the plant capacity factor including turnover for a 25 years project have benefited to investors. Currently, the installed capacity of solar PV farm in Thailand have increased; however, the size of installed capacity has mostly as VSPP (about 92%) beyond independent power producer (IPP) and small power producer, as shown in Figure 2.

Updated total solar PV farm year 2016 in each province of each region in Thailand was gathered data from ERC. Regional arranging from highest to lowest in numbers of stations and capacity were as follows: Highest was the Central region at 274 plants with a total capacity of 1636 MW, Northeastern region at 75 plants with a total capacity of 392 MW and the lowest was the Northern region at 43 plants with a total capacity of 630 MW, as shown in Table 1. However, there was no registration of solar PV farm in the Southern region due to the crisis and terrorist situation. Lopburi and Kanchanaburi in the Central region, Nakorn Sawan in the Northern region, KhonKaen, Ubon Rachathani and Nakorn Rachasima in the Northeastern region have expanded the installation capacity for 3–4 years. Meanwhile, Phetchaburi, Saraburi and Suphanburi in the Central region, Tak, MaeHongSon, Kampangpetch in the Northern region, and Udonthani, SriSaKet, BuriRum, Chaiyaphum in the Northeastern have two consecutive years of capacity expansion. In present, the cumulative PV capacity at the end of year 2016 is 2660 MW.

The largest capacity of solar PV farm installed during year of 2009–2016 was 506 MW, while the smallest capacity was 11 MW. Most of solar PV farm in Thailand was located in the central region about 70%, followed by Northeast 19%, and North 20%, respectively. This is because the central area is suitable for both the intensity of the solar radiation and the wires that can be installed and sold the electricity to the government.

The frustrated of solar PV farm has main factor from government policy and depends on natural disaster in Thailand. Adder program has changed the rate of subsidy from 0.25 USD/kWh to 0.20 USD/kWh in year of 2010. In 2013, the announcement of Feed-in-Tariff (FiT) for solar energy was delayed due to the government needs to

**Figure 1:** Overview number and capacity of solar photovoltaic farm in Thailand [15]

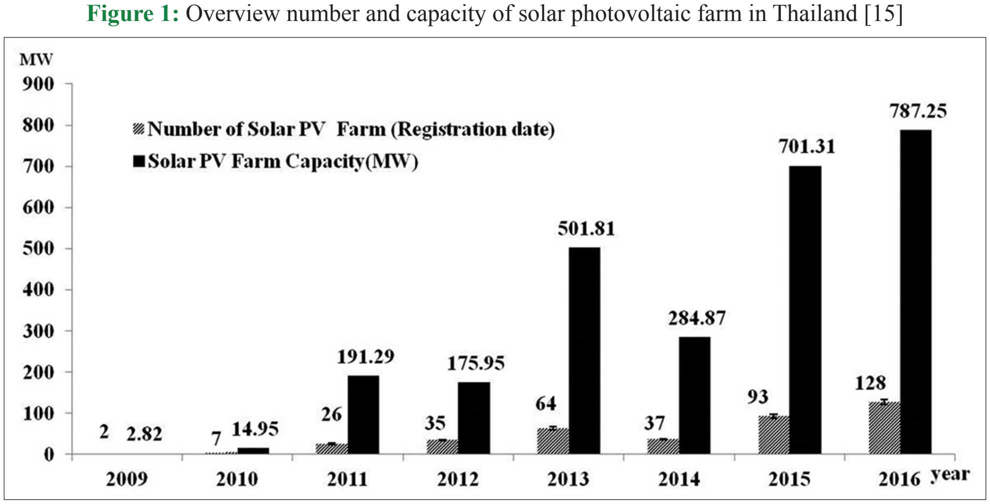


**Table 1: Number of stations, capacity and location of solar farms during the year 2009–2016 in each regions of Thailand (ERC, 2011)**

| Province | Capacity (MW) | | | | | | | | Total capacity | No. of solar PV farm |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | | |
| Ang Thong | | 1 | | | 10 | | 2 | 7 | 20 | 5 |
| Chachoengsao | 1 | | | | | | | 9 | 10 | 3 |
| Chai Nat | | | | 7 | | | | | 7 | 1 |
| Chanthaburi | | | | | | | | 7 | 7 | 2 |
| Chon Buri | | | | | | 30 | | 5 | 35 | 7 |
| Kanchanaburi | | | | 11 | 11 | 26 | 42 | | 90 | 13 |
| Lop Buri | | 3 | 64 | 18 | 22 | | 61 | 6 | 174 | 23 |
| Nakhon Nayok | | | | | | | | 7 | 7 | 2 |
| Nakhon Pathom | | | 8 | 17 | 60 | | 87 | 14 | 186 | 23 |
| Nakhon Nayok | | | | | 10 | | | | 10 | 1 |
| Nonthaburi | | | | | | | | 8 | 8 | 2 |
| Pathomthani | | | | | | | 2 | 18 | 20 | 5 |
| Phetchaburi | | 2 | | | | | 156 | 45 | 203 | 39 |
| Prachinburi | | | 12 | | | 25 | 28 | 37 | 102 | 15 |
| Prachup Khiri Khan | | 2 | | | | | 34 | 51 | 87 | 19 |
| Pranakorn Sri Ayutthaya | | | 41 | | 34 | 10 | 5 | 37 | 127 | 17 |
| Ratchaburi | | | | | 3 | | 8 | 13 | 24 | 7 |
| Rayong | | | | 2 | | | | 6 | 8 | 2 |
| Sa Kaeo | | | | | | | | 280 | 280 | 48 |
| Samut Prakarn | | | | | | | | 8 | 8 | 2 |
| Samut Sakorn | | | | | | | 32 | 30 | 62 | 11 |
| Samut Songkhram | | | | | | | | 9 | 9 | 2 |
| Saraburi | | | 6 | 14 | 11 | | 24 | 22 | 77 | 13 |
| Suphan Buri | | | 8 | | 50 | 9 | 8 | 5 | 80 | 12 |
| Total Central region | 1 | 8 | 139 | 69 | 211 | 100 | 489 | 624 | 1641 | 274 |
| Chiang Mai | | | | | | | | 5 | 5 | 1 |
| Chiang Rai | | | | 4 | | | | | 4 | 1 |
| Kampang Pet | | | | | 20 | 20 | | | 40 | 4 |
| Lampang | | | | | 1 | | 135 | 1 | 137 | 4 |
| Lampoon | | | | | 1 | | 8 | | 9 | 2 |
| Mae Hong Sorn | | | | 1 | 3 | | | | 4 | 4 |
| Nakorn Sawan | | | 13 | | 126 | | 15 | | 154 | 5 |
| Phare | | | | | | | | 8 | 8 | 1 |
| Phetchabon | | | | | 10 | | | | 10 | 1 |
| Phetchabun | | 3 | 5 | | 10 | | | | 18 | 4 |
| Phetchabun | | | | | | | 8 | | 8 | 1 |
| Phichit | | | | | 5 | | 46 | | 51 | 8 |
| Phitsanulok | | | | | | | | 134 | 134 | 1 |
| Su Kho Thai | | | | | | 10 | | | 10 | 1 |
| Tak | | | | | 6 | 20 | | 11 | 37 | 5 |
| Total North region | 0 | 3 | 18 | 5 | 182 | 50 | 212 | 159 | 629 | 43 |
| Bengkard | | | | | | 7 | | | 7 | 1 |
| Buri Ram | | | | | 21 | 32 | | | 53 | 7 |
| Chaiyaphum | | | | | 51 | 12 | | | 63 | 12 |
| Kalasin | | | | | | 2 | | | 2 | 2 |
| Khon Kaen | | | | 30 | 18 | 17 | 1 | | 66 | 16 |
| Loei | | | 6 | | | 7 | | | 13 | 2 |
| Nakhon Phanom | | | 6 | | | 15 | | | 21 | 3 |
| Nakhon Rachasima | | 5 | 11 | 45 | 6 | | | 5 | 72 | 15 |
| Nakhon Rachasima | | | | | | 12 | | | 12 | 1 |
| Nong Kai | | | | | 1 | | | | 1 | 1 |
| Roi Et | | | | 8 | | | | | 8 | 1 |
| Sakonakorn | | | | | | 7 | | | 7 | 1 |
| Sakonakorn | | | 6 | | | | | | 6 | 1 |
| Si Sa Ket | | | 6 | 11 | | | | | 17 | 3 |
| Surin | | | | 3 | | 7 | | | 10 | 2 |
| Ubon Ratchathani | | | | 5 | 3 | 13 | | | 21 | 4 |
| Udon Thani | 2 | | | 1 | 7 | | | | 10 | 3 |
| Total Northeast | 2 | 5 | 35 | 103 | 107 | 131 | 1 | 5 | 389 | 75 |
| Total (Thailand) | 3 | 16 | 192 | 177 | 500 | 281 | 702 | 788 | 2659 | 392 |

more studies pros and cons of the program. Moreover, the rate of FiT was changed to be 6.16 THB/kWh (capacity >10–250 kWh) and 6.55 THB/kWh (capacity >250–1,000 kWh). This can affect to the investment attraction on solar PV farm decreased. In addition, Thailand has suffered from big flooding in 2011, which may affect to solar PV farm reduced in year of 2012.

## 2. METHODOLOGY

### 2.1. Primary Data Collection

Completed questionnaires submitted to private solar PV farm for primary data collection which were separated according to the type of solar cell. The questionnaires were sent to 200 polycrystalline silicon (PCSS) solar PV farm and 25 amorphous silicon thin-film solar PV farm. After that, the researchers took random samples to analyze the objective research of 20 plants which were selected from 10 plants each of the PCSS solar PV farm and the amorphous thin-film solar PV farm.

### 2.2. Secondary Data Collection

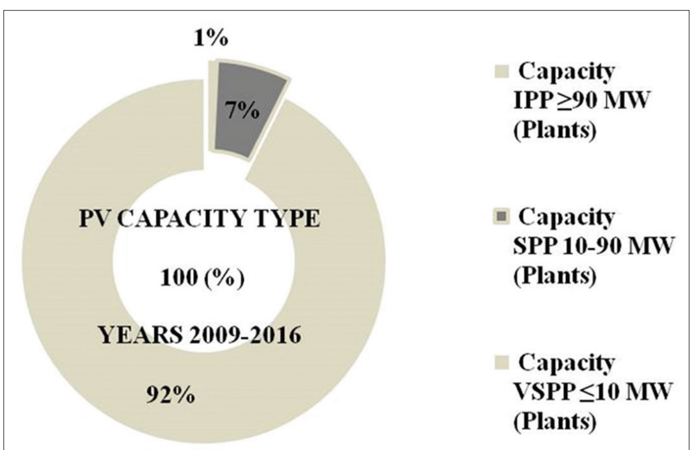
The relevant secondary data were gathered from reliable sources. The capacity of solar cell in Thailand was obtained from the ERC. The related data about renewable energy policy, PDP, and etc., were collected from the Department of Alternative Energy the Development and Efficiency (DEDE), the Metropolitan Electricity Authority, the Provincial Electricity Authority, academic research, dissertation, and Journal and/or other related articles/reports from the internet.

### 2.3. Calculation of Plant Capacity Factor and Performance Raito

According to the ERC's announcement for Environmental and Safety Assessment in the renewable solar energy sector (Jäger-Waldau, 2012), the private solar PV farm must design with a plant capacity factor of at least 15 % and a performance ratio >75% (Tanpipat, 2011). The plant capacity factor (%) and the performance ratio (%) can be calculated as shown in Equations (1) and (2):

$$\text{Plant capacity factor}(\%)= \left[ (MWh_{AC}) \Big/ (MWh_{DC} \times \text{Production Hours}) \right] \times 100 \quad (1)$$

Figure 2: Size of installed capacity of solar photovoltaic farm in Thailand (ERC, 2011)




Where $MWh_{AC}$/year represents the actual annual electricity production, and $MWh_{DC}$ is the capacity of solar cell plant.

$$\text{Performance ratio}(\%)= \left[ \frac{\text{Actual production of electricity} \big/ \text{Year Alternating current-AC}}{\text{Calculation of electricity} \big/ \text{Year direct current-DC}} \right] \times 100 \quad (2)$$

As shown in Table 2, the ten of PCSS solar PV farm have a performance ratio between 82-84% and a plant capacity factor between 17–18%, respectively.

Table 3 displays the ten of amorphous silicon thin film (ASTF) solar PV farm, which have a performance ratio between 80–83% and a plant capacity factor between 15–16%, respectively.

### 2.4. Investment Analysis

A private company usually considers the cash outcome to recover their initial investment along with the decision of where to invest their fund. The indicated parameter of the investment research in this paper inclusive as hereunder.

#### *2.4.1 IRR (MoE, 2011)*

This parameter is the project ratio return under the loan interest's rate and a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. If the result of IRR is higher than the return profit, the project has to

**Table 2: Performance ratio and plant capacity factor of the PCSS solar PV farm**

| Plant | PCSS solar PV farm | |
|---|---|---|
| | Performance ratio (%) | Plant capacity factor (%) |
| 1 | 83 | 17 |
| 2 | 82 | 18 |
| 3 | 84 | 18 |
| 4 | 83 | 18 |
| 5 | 84 | 18 |
| 6 | 84 | 17 |
| 7 | 84 | 18 |
| 8 | 84 | 18 |
| 9 | 84 | 18 |
| 10 | 83 | 18 |

PCSS: Polycrystalline silicon, PV: Photovoltaic

**Table 3: Performance ratio and plant capacity factor of the ASTF solar PV farm**

| Plant | ASTF solar PV farm | |
|---|---|---|
| | Performance ratio (%) | Plant capacity factor (%) |
| 1 | 80 | 15 |
| 2 | 82 | 16 |
| 3 | 84 | 16 |
| 4 | 84 | 16 |
| 5 | 83 | 16 |
| 6 | 82 | 16 |
| 7 | 82 | 16 |
| 8 | 83 | 15 |
| 9 | 83 | 15 |
| 10 | 83 | 15 |

ASTF: Amorphous silicon thin film, PV: Photovoltaic be reconsidered before beginning the project. On the other hand, when the IRR' calculation has a high return profit in consequence under the satiation of a low-interest rate, the project will have a higher return. IRR calculations rely on the same formula as NPV as hereunder.

$$\mathrm{NPV}=\sum_{t-1}^{T}\frac{C_t}{(1+r)^t}-C_0 \tag{3}$$

$C_t$ = net cash inflow during the period t, $C_0$=total initial investment costs, r = discount rate, and t= number of time periods.

### 2.4.2. PB

The PB determines the time to recover the cash inflows generated by the initial overall investment less the overhead and expenses during the project operation. The calculation of PB was shown in Equation (3). The unit of PB is by year. The short-recovery period means the project has a good profit in a relatively short time period.

$$\text{Payback period}={}^{\text{TIC}}\!/_{\text{NCF}} \tag{4}$$

Where TIC represents to initial investment, and NCF represents to Cash inflow (USD/Year). The theory of PB must be shorter than the project age. In practice, the mega solar project accepts 7–8 years for the PB.

### 2.4.3. Cash flow

Cash flow evaluates the cost and expenses compared with the turnover. A cash flow calculation for the project is important because the project owner can resolve and plan to avoid a shortage of money for the project and do not cause project disruptions due to a lack of funds. The relevant elements affecting the proper capital investment are the cost and the expenses during the project period. While the investment cost of a solar project consisted of land preparation, photovoltaic module, inverter, transformer, connection system, cable, structure and installation, engineering, supplier, construction, fence, ditch and utilities, the operating cost consisted of gasoline expense for lawn remover, public supply cost for PV's cleaning and electrical system, telephone system and network cost, and etc. However, the cost and expenses vary depending on the selective technology, size of the project and government support scheme (Hachigami, 2015; Suthiwongwong, 2011).

## 3. RESULTS AND DISCUSSION

The surveyed data was supported by private solar PV farm in each 10 of PCSS solar PV farm and ASTF solar PV farm. The location and commercial operation date (COD) of each survey data also show in Table 4. PB, IRR, and Turnover of ASTF and PCSS were analyzed. The currency applied in this paper refers to the average of exchange rate during year 2012. Therefore, the exchange rate was 32.4 USD/THB. Output analysis was based on hours/year at 8640 h. Output analysis resulted of PCSS is more than ASTF at 16% in average output along 25 years, as shown in Table 4. Energy output from solar cell depends on PV efficiency. Because the efficiency of PCSS is higher than ASTF around 50%, the output of PCSS shows higher result than ASTF.

After analyzed data, the result found that the average data of investment, PB, IRR, and turnover from ten samples of PCSS were 3.61 million USD, 8.40 years, 9.40%, and 5.97 million USD, respectively (Table 5). Meanwhile, the average data from ten samples of ASTF were 3.03 million USD, 8.76 years, 9.58%, and 4.66 million USD, consecutively (Table 6). The investment cost of PCSS was in a range of 3.45–3.7 USD per MW, which has PB about 8.35–8.74 years, and 8.97–10.01% of IRR. The income along 25 years was around 5.57–6.13 million USD. In case of ASTF, the investment cost was in a range of 2.79–3.20 US$ per MW, with PB of 8.56–9.00 years, and 9.31–10.02% of IRR. The income along 25 years project was around 4.20–5.01 Million USD.

The average PB and IRR data of ASTF and PCSS were nearly the same result, while the turnover of PCSS was greater than ASTF by adding 8% of investment cost from ASTF and increasing 19% turnover compared with ASTF. In comparison of PB between ASTF and PCSS, the result indicated that PB of PCSS was slightly longer than ASTF. In case of IRR, PCSS has IRR less than ASTF about 2%. However, the average data of PB and IRR showed that the result was nearly the same outcome between PCSS and ASTF. Therefore, PB and IRR are not significant difference on the investment of PCSS and ASTF. Both of PCSS and ASTF, they have PB and IRR around 8 years, and 9%, respectively.

In comparison of investment cost and cash flow, this study selected each one of solar PV farm from PCSS and ASTF that have the same COD date during year 2012. As shown in Table 7,

**Table 4: Analysis output in 25 years of PCSS and ASTF**

| No. | PCSS | | | ASTF | | |
|---|---|---|---|---|---|---|
| | COD | Location | Average output MWh/year | COD | Location | Average output MWh/year |
| 1 | 2012 | Roi Et | 1,135 | 2012 | Prachin Buri | 912 |
| 2 | 2012 | NakornPathom | 1,222 | 2011 | Ayutthaya | 997 |
| 3 | 2012 | NakornPathom | 1,149 | 2013 | Buri Ram | 1,021 |
| 4 | 2012 | NakornPathom | 1,145 | 2013 | Buri Ram | 1,021 |
| 5 | 2012 | NakornPathom | 1,149 | 2012 | Suphanburi | 1,009 |
| 6 | 2012 | Korat | 1,085 | 2012 | Nakornpathom | 997 |
| 7 | 2013 | Loei | 1,149 | 2012 | Suphanburi | 997 |
| 8 | 2014 | Khon Kaen | 1,149 | 2013 | Lobburi | 946 |
| 9 | 2014 | Khon Kaen | 1,149 | 2013 | Ayutthaya | 946 |
| 10 | 2014 | Surin | 1,135 | 2013 | Ayutthaya | 946 |
| Average | | | 1,137 | Average | | 979 |

PCSS: Polycrystalline silicon, ASTF: Amorphous silicon thin film, COD: Commercial operation date

**Table 5: Conclusion of analysis of PB, IRR and turnover 25-years for PCSS solar PV farm**

| PCSS Plant | Investment/MW Million (USD) | PB Year | IRR % | Turnover 25 year Million (USD) | Performance ratio (%) | Plant factor (%) |
|---|---|---|---|---|---|---|
| 1 | 3.45 | 8.74 | 10.01 | 5.49 | 83 | 18 |
| 2 | 3.64 | 8.38 | 9.11 | 5.89 | 82 | 18 |
| 3 | 3.67 | 8.35 | 9.35 | 6.13 | 84 | 18 |
| 4 | 3.70 | 8.36 | 9.10 | 6.09 | 83 | 18 |
| 5 | 3.67 | 8.35 | 9.34 | 6.13 | 84 | 18 |
| 6 | 3.55 | 8.43 | 8.97 | 5.57 | 84 | 17 |
| 7 | 3.58 | 8.35 | 9.70 | 6.13 | 84 | 18 |
| 8 | 3.61 | 8.35 | 9.59 | 6.13 | 84 | 18 |
| 9 | 3.64 | 8.35 | 9.47 | 6.13 | 84 | 18 |
| 10 | 3.61 | 8.36 | 9.41 | 6.01 | 83 | 18 |
| Average | 3.61 | 8.40 | 9.40 | 5.97 | 84 | 18 |

PCSS: Polycrystalline silicon, PV: Photovoltaic, PB: Payback period, IRR: Internal rate of return

**Table 6: Conclusion of analysis of PB, IRR and turnover 25-years for ASTF solar PV farm**

| ASTF | | | | | | |
|---|---|---|---|---|---|---|
| Plant | Investment/MW Million (USD) | PB Year | IRR (%) | Turnover 25 year Million (USD) | Performance ratio (%) | Plant factor (%) |
| 1 | 2.79 | 8.92 | 9.60 | 4.20 | 80 | 15 |
| 2 | 3.15 | 8.65 | 9.31 | 4.80 | 82 | 16 |
| 3 | 3.20 | 8.56 | 9.44 | 5.01 | 84 | 16 |
| 4 | 3.20 | 8.56 | 9.44 | 5.01 | 84 | 16 |
| 5 | 3.18 | 8.60 | 9.36 | 4.91 | 83 | 16 |
| 6 | 3.15 | 8.65 | 9.31 | 4.80 | 82 | 17 |
| 7 | 3.15 | 8.65 | 9.31 | 4.80 | 82 | 17 |
| 8 | 2.82 | 9.00 | 10.02 | 4.36 | 84 | 16 |
| 9 | 2.82 | 9.00 | 10.01 | 4.36 | 84 | 16 |
| 10 | 2.82 | 9.00 | 10.01 | 4.36 | 84 | 16 |
| Average | 3.03 | 8.76 | 9.58 | 4.66 | 83 | 16 |

ASTF: Amorphous silicon thin film, PV: Photovoltaic, PB: Payback period, IRR: Internal rate of return

**Table 7: Comparison investment cost of solar PV farm between PCSS and ASTF**

| No. | Description 1: Construction cost | ASTF Million (USD)/MW | PCSS Million (USD)/MW |
|---|---|---|---|
| 1 | Capacity (MW) | | |
| 2 | Preparation of land | 0.08 | 0.08 |
| 3 | Photovoltaic module | 1.34 | 2.01 |
| 4 | Inverter | 0.39 | 0.45 |
| 5 | Transformer | 0.03 | 0.03 |
| 6 | Connection system, cable, structure and installation | 0.74 | 0.68 |
| 7 | Engineering, supplier, and construction | 0.15 | 0.15 |
| 8 | Fence, ditch and utilities | 0.06 | 0.06 |
| | Total investment | 2.79 | 3.45 |
| **No.** | **Description 2: Operation cost per year** | **USD/year** | **USD/year** |
| 1 | Salary for all employee | 18,518.52 | 18,518.52 |
| 2 | Gasoline expense for lawn mover | 1,111.11 | 1,111.11 |
| 3 | Public supply cost for PV's cleaning | 1,851.85 | 1,851.85 |
| 4 | Public supply cost for electrical system | 7,407.41 | 7,407.41 |
| 5 | Telephone system and network cost | 3,703.70 | 3,703.70 |
| 6 | All risk insurance | 3,343.70 | 4,144.44 |
| 7 | Ground rent per month | 2,962.96 | 2,962.96 |
| 8 | Other expenses | 370.37 | 370.37 |
| | Total operation cost per year | 39,269.63 | 40,070.37 |
| **No.** | **Item description 3: Data solar PV farm (data by feed)** | | |
| 1 | Performance ratio (%) | 80 | 83 |
| 2 | Plant capacity factor (%) | 15 | 18 |

ASTF: Amorphous silicon thin film, PCSS: Polycrystalline silicon, PV: Photovoltaic

the construction cost and operation cost of ASTF was lower than PCSS. It seems that ASTF solar PV farm has shown the benefit financial beyond PCSS. This is because the module of PCSS was expensive than ASTF, which was directly affect to the total investment cost due to be the largest portion (Figure 3). The estimate cost of ASTF was around 0.83–0.93 USD/W, while

**Table 8: Cash flow, cash collection and IRR of PCSS in 25 years project**

| Year | Christian era | Cash flow (Million USD) | Cash collection (Million USD) | IRR (%) |
|---|---|---|---|---|
| 0 | 2012 | −3.4537 | −3.4537 | - |
| 1 | 2013 | 0.4181 | −3.0356 | −88 |
| 2 | 2014 | 0.4131 | −2.6225 | −58.84 |
| 3 | 2015 | 0.4081 | −2.2144 | −37.94 |
| 4 | 2016 | 0.4031 | −1.8113 | −24.39 |
| 5 | 2017 | 0.3981 | −1.4131 | −15.42 |
| 6 | 2018 | 0.3931 | −1.0200 | −9.25 |
| 7 | 2019 | 0.3881 | −0.6318 | −4.87 |
| 8 | 2020 | 0.3831 | −0.2487 | −1.66 |
| 9 | 2021 | 0.3781 | 0.1294 | 0.75 |
| 10 | 2022 | 0.3731 | 0.5025 | 2.60 |
| 11 | 2023 | 0.3681 | 0.8706 | 4.04 |
| 12 | 2024 | 0.3631 | 1.2336 | 5.18 |
| 13 | 2025 | 0.3580 | 1.5917 | 6.09 |
| 14 | 2026 | 0.3530 | 1.9447 | 6.83 |
| 15 | 2027 | 0.3480 | 2.2926 | 7.43 |
| 16 | 2028 | 0.3429 | 2.6355 | 7.93 |
| 17 | 2029 | 0.3379 | 2.9734 | 8.35 |
| 18 | 2030 | 0.3328 | 3.3062 | 8.69 |
| 19 | 2031 | 0.3278 | 3.6340 | 8.98 |
| 20 | 2032 | 0.3227 | 3.9567 | 9.23 |
| 21 | 2033 | 0.3176 | 4.2743 | 9.44 |
| 22 | 2034 | 0.3126 | 4.5869 | 9.62 |
| 23 | 2035 | 0.3075 | 4.8944 | 9.77 |
| 24 | 2036 | 0.3024 | 5.1968 | 9.90 |
| 25 | 2037 | 0.2973 | 5.4941 | 10.01 |

The data occurred on the table was collected from PCSS solar PV farm site, Roi Et province. Total investment 27.26 million USD, COD: June 2012, original capacity 8 MW, PB=8.74 years, IRR=10.01%, Turnover 25 years=5.49 Million USD. IRR: Internal rate of return, PV: Photovoltaic, PB: Payback period, COD: Commercial operation date, PCSS: Polycrystalline silicon

**Table 9: Cash flow, cash collection and IRR of ASTF in 25 years project**

| Year | Christian Era | Cash flow (Million USD) | Cash collection (Million USD) | IRR (%) |
|---|---|---|---|---|
| 0 | 2012 | −2.7864 | −2.7864 | - |
| 1 | 2013 | 0.3287 | −2.4577 | −88 |
| 2 | 2014 | 0.3247 | −2.1330 | −59.46 |
| 3 | 2015 | 0.3206 | −1.8125 | −38.65 |
| 4 | 2016 | 0.3165 | −1.4960 | −25.10 |
| 5 | 2017 | 0.3124 | −1.1835 | −16.10 |
| 6 | 2018 | 0.3083 | −0.8752 | −9.91 |
| 7 | 2019 | 0.3042 | −0.5710 | −5.49 |
| 8 | 2020 | 0.3001 | −0.2708 | −2.25 |
| 9 | 2021 | 0.2960 | 0.0252 | 0.18 |
| 10 | 2022 | 0.2919 | 0.3171 | 2.05 |
| 11 | 2023 | 0.2878 | 0.6050 | 3.51 |
| 12 | 2024 | 0.2837 | 0.8887 | 4.67 |
| 13 | 2025 | 0.2796 | 1.1683 | 5.59 |
| 14 | 2026 | 0.2755 | 1.4437 | 6.34 |
| 15 | 2027 | 0.2713 | 1.7151 | 6.96 |
| 16 | 2028 | 0.2672 | 1.9823 | 7.47 |
| 17 | 2029 | 0.2631 | 2.2453 | 7.89 |
| 18 | 2030 | 0.2589 | 2.5043 | 8.25 |
| 19 | 2031 | 0.2548 | 2.7591 | 8.54 |
| 20 | 2032 | 0.2506 | 3.0097 | 8.80 |
| 21 | 2033 | 0.2465 | 3.2562 | 9.01 |
| 22 | 2034 | 0.2423 | 3.4985 | 9.19 |
| 23 | 2035 | 0.2382 | 3.7367 | 9.35 |
| 24 | 2036 | 0.2340 | 3.9707 | 9.48 |
| 25 | 2037 | 0.2298 | 4.2005 | 9.60 |

The data occurred on the table was collected from ASTF solar PV farm site, Prachin Buri province. Total investment 22.28 million USD, COD: June 2012, original capacity 8 MW. PB=8.92 year, IRR=9.60%, and Turnover 25 year=4.20 million USD. IRR: Internal rate of return, PV: Photovoltaic, PB: Payback period, COD: Commercial operation date, ASTF: Amorphous silicon thin film

PCSS was around 1.02–1.24 USD/W, respectively. Meanwhile, the levelized cost of energy of PCSS was between 0.25 and 0.65 (USD/kWh) which was longer than ASTF (0.26–0.59 USD/kWh) (Sahay et al., 2013).

Figure 4 shows the percentage of operation cost in each of item. It can be noticed that the largest portion of operation cost was come from the expense of salary for employee (46.21%), followed by public supply cost for electrical system (18.49%), and all risk insurance (10.34%), respectively.

It is well known that there are two types of return on investment: Economic and financial returns. In case of government agencies, as non-profit organization, they will consider both the economic and financial implications for investment considerations in order to maximize the value of the project to the public according to the government mission, while the private investment will often consider only financial return. This study only considers the views of private investors.

The result of comparative solar PV farm investment was shown in Tables 8 and 9. This study assumed that the solar system has deteriorated which resulted in the decrease of electricity production yield, approximately 1% annually. It was noticed that the profit was occurred at 9$^{th}$ year of project operation. Revenues of the project was come from electricity sales at 0.35 USD per unit (0.25 USD adder prices and 0.11 USD for selling prices). Cash flow depends on the productivity of each type of solar power plant. In this paper, the output analysis of PCSS was more than ASTF since year 2012–2037. Hence, the result of analysis on IRR of PCSS was also higher than ASTF. As a result, the final income/turnover of PCSS is better than ASTF. However, it should be recognized that solar cell has life cycle around 25 years, but solar cell is deteriorating every year. Therefore, maintenance and insurance costs are required during the year, which will be part of the lifetime operating costs.

## 4. CONCLUSIONS

This research has investigated the economic potential of solar PV farm in Thailand. The primary data were collected from 20 solar PV farm plants, which included investment data, type of solar cell, and data analysis. After analysis, four main investment costs of PCSS solar PV farm are identified: (1) Photovoltaic module; (2)

**Figure 3:** Construction cost of the polycrystalline silicon solar photovoltaic farm per MW

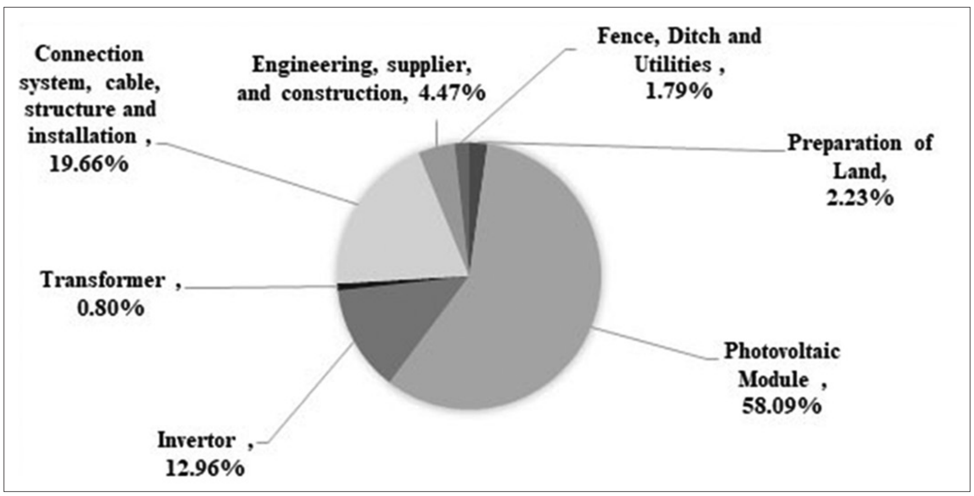
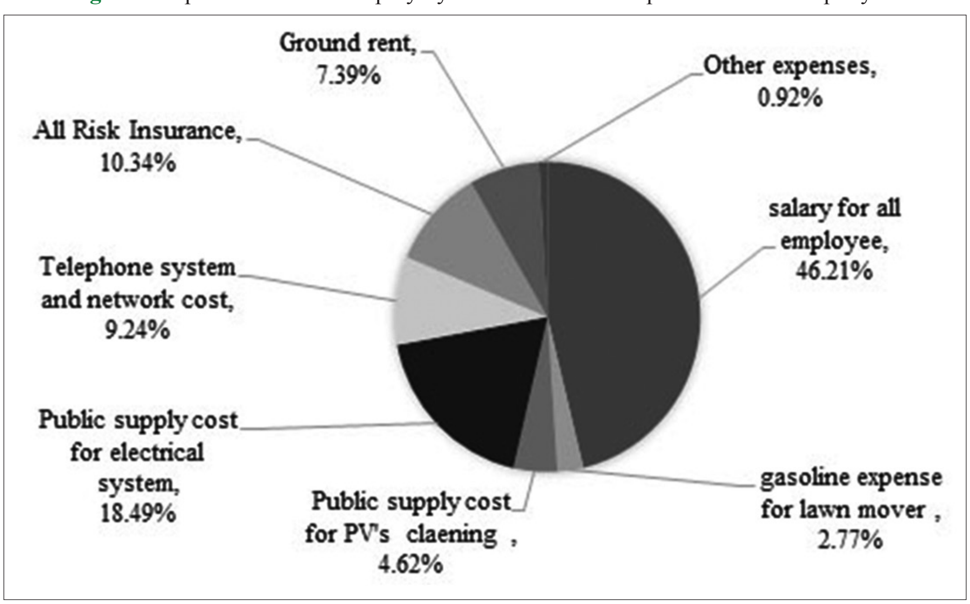



**Figure 4:** Operation cost of the polycrystalline silicon solar photovoltaic farm per year



connection system; (3) inverter, and (4) engineering construction, distributed as 58.09%, 19.66%, 12.96%, and 4.47%, respectively. In addition, four main operation costs of the PCSS solar PV farm are also recognized: (1) Salary for all employees; (2) public supply cost for electrical system; (3) all risk insurance, and (4) telephone and network system, distributed as 46.21%, 18.49%, 10.34%, and 9.24%, respectively. When compared the economic potential between PCSS and ASTF, PCSS provide more profit than ASTF because of having short PB and more turnovers.

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