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An Analysis for Promoting Residential-scale Solar Photovoltaic (PV) in Bangkok, Thailand

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An Analysis for Promoting Residential-scale Solar Photovoltaic (PV) in Bangkok, Thailand

by

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Abstract

An Analysis for Promoting Residential-scale Solar Photovoltaic (PV) in Bangkok, Thailand

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Solar Photovoltaic (PV) has a significant potential for distributed energy in the urban environment of Bangkok, Thailand in order to decrease the country's reliance on imported conventional energy and enhance the country's energy security. This research analyzes the technical, economic and policy analysis of installing 3,000 MW (Thailand's solar PV goal) of residential solar PV in Bangkok using System Advisor Model (SAM) and also compares each analysis to large-scale load (e.g. manufacturing). In technical analysis, the relationship of distributed solar energy and electric load from the grid is analyzed. While the residential load and peak solar irradiance are not correspondent for residential scale, generating electricity from 3,000 MW of solar PV can still decrease residential daily load consumption from the grid by 38 percent. On the other hand, the distributed of solar energy and large-scale load are well matched. As a result, the large-scale peak load can be reduced by 16.7 percent from 3,000 MW solar installation. Regarding to economic analysis, the levelized cost of energy of residential scale is higher

than large scale. Without tariff, costs of solar electricity are higher than grid price. Therefore, it is necessary to introduce solar tariff to encourage people to install solar PV. Throughout solar project's lifetime, with current Thailand's solar incentives (Feed-in Tariff; FIT), solar project investments of both scales seem feasible from financial perspectives under Thai's government cost assumptions. In addition, due to the increasing urbanization rate and typical land use of Bangkok, residential solar PV seems to be the better candidate. However, some technical and policy barriers remain, such as the lacks of skilled manpower, policy mix, and financing options as well as the inconsistence of governmental support. It is essential for Thai government to overcome these barriers in order to create sustainable growth of solar PV in the country.

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Chapter 1: Introduction

1.1 Background

Conventional energy sources, such as natural gas, coal, and oil supply almost 80 percent of today global energy consumption. Also, within the next 20 years, global energy consumption will increase approximately 20 percent, while, non-renewable energy will deplete (U.S. Energy Information Administration, 2015a). The growing demand for energy creates significant challenges for all nations to secure energy for their social and economic activities. Therefore, it is crucial to strengthen energy security by using renewable energy as much as possible in order to reduce both domestic and imported conventional energy. Many government and private researchers have developed low carbon-based energy sources to increase opportunities for green growth.

In Thailand, the country electricity generation relies mostly on fossil fuels. Natural gas has the largest proportion (almost 70 percent) of energy supply, while renewable energy shares a very low percentage at approximately less than 5 percent (Department of Alternative Energy Development and Efficiency, 2012). Environmental issues from utilizing fossil fuel energy sources have also created concerns on carbon dioxide (CO_2) emission that relate to global warming. During 2006-2011, carbon dioxide emission per capita increased around 12.5 percent from 4.0 to 4.5 ton per capita per year (the World Bank, 2015). Compared to the world average, during the same period of time, the increasing rate of carbon dioxide emissions is higher for Thailand than the world overall. Based on the World Bank (2015), from 2006 to 2011, the world average carbon dioxide emission boosted from 4.6 to 4.9 ton per capita per year, which is approximately a 6.5 percent increase. The connection between CO_2 emission and climate change came to the forefront of Thailand's consciousness due to their natural disasters in recent history. Thus, it is necessary for Thailand to decrease CO_2 emission rate by introducing low-carbon energy resources into the country's power generation mix.

Thailand is also facing an energy security problem from high dependence (more than 50 percent of total primary energy supply) on imported non-renewable energy resources due to continuous depletion of domestic energy reserves simultaneously with a significant increase in electricity demand. During 2014, Thailand held 0.449 billion barrels of proven crude oil reserves, which decreased from 0.516 billion barrels in 2002. As same as natural gas, as of 2014, natural gas reserve was 9.039 trillion cubic feet, which reduced from 12.705 trillion cubic feet from 2002, while Thailand's electricity peak demand in 2013 was approximately 25,000 MW, which increased from around 15,000 MW in 2000(Department of Alternative Energy Development and Efficiency, 2013; Chaianong and Pharino, 2015 and U.S. Energy Information Administration, 2015b). Additionally, the fluctuation fuel costs combined with a lack of diversity in power generation mix leads to a production cost risk and energy security problem. Integration of a wider variety of energy resource types, including renewable energy, could be a cost-effective approach to managing the risks.

Among renewable energy sources, in Thailand, solar energy has a high potential due to the good solar resources near the Equator; however, it can be utilized only in daytime with high installation cost and limited efficiency. The solar energy applications can be divided into two main categories: solar thermal application and photovoltaic (PV) technologies. Solar thermal is the conversion of solar radiation into heat, which uses solar collectors and concentrators to collect solar radiation. Solar thermal is widely utilized in industries as water heating, distillation, wastewater treatment and heating/cooling of buildings (Mekhilef *et al.*, 2011). The other type is a photovoltaic (PV) system, which converts solar radiation into electricity using semiconductor materials. Photovoltaic systems can be installed in both large quantities for utilities (grid-connected/centralized system) and small quantities for residential and/or commercial scale (off-grid/decentralized system). Furthermore, there are two main types of solar panel based on materials used. The first type is "crystalline", which is relatively efficient but cannot endure in highly sensitive environment, such as very low or high temperature and/or moisture. The second type is "thin-film", which is lower efficiency; however, this type of panel can be used in highly sensitive condition (Timilsina *et. al,* 2012).

Energy generation from solar has been successfully implemented in many countries such as Germany, Spain, China and the United States. For instance, in 2012, Germany installed 7.6 Gigawatt-peak (GWp) with 184,298 PV systems. Total solar PV systems in Germany shared around 4 percent of overall electricity production. (Germany Trade and Invest, 2013). As for the United States (U.S.), in the second quarter of 2015, the total solar installed capacity was 22.7 GW. Also, solar PV shared around 16 billion kWh, which is 0.4 percent of U.S.'s power generation mix in 2014. (U.S. Energy Information Administration**,** 2015c and Solar Energy Industries Association, 2014). In Thailand, in 2013, the installed capacity of solar power generation was approximately 2,700 MW, which increased more than 110 percent from 2012 (Department of Alternative Energy Development and Efficiency, 2013; Chaianong and Pharino, 2015). However, due to, the high capital costs of solar installation and the lower level of awareness of green energy, the solar PV installation rate in Thailand is still very low compared to other countries, such as Germany, the U.S., Japan and China.

This work focuses on the feasibility analysis of solar PV in residential areas of Bangkok, Thailand by analysing the relationship between electricity demands and solar radiation in order to estimate the possibility of distributed solar PV in Bangkok. An economic analysis quantifies any policies (e.g., value of solar tariff) related to household income and economic growth are needed to encourage Thai people to install solar PV. We also compare PV costs to other electricity generator sources, such as coal and natural gas to better understand how to improve solar incentive policies there. Furthermore, in order to understand this analysis more effectively, the large scale of solar PV is also investigated to make a comparison with the residential scale.

1.2 Study Objectives

The objectives of this study are as follows:

1. Investigate the feasibility analysis of solar PV in residential areas of Bangkok, Thailand by focusing on technical analysis, economic analysis, and policy analysis.
2. Compare the feasibility analysis of residential-scale and large-scale solar PV in Bangkok, Thailand.
3. Suggest the potential incentives or policies to encourage Thai residents to install solar PV.

1.3 Structure of Thesis

This thesis presents the research in seven chapters.

Chapter 1 is the introduction of research problems.

Chapter 2 provides the background of energy and electricity situation in Thailand.

Chapter 3 discusses the technical analysis of solar PV in Bangkok to understand the relationship between electricity demands and solar radiation.

Chapter 4 analyses the economic aspect in terms of Levelized Cost of Energy (LCOE) related to household income and economic growth, and compares PV costs to other electricity generator sources, such as coal and natural gas.

Chapter 5 introduces the policy analysis by using the economic analysis to calculate cash flows and other financial indicators, such as Net Present Value (NPV), Payback Period (PBP), and Internal Rate of Return (IRR) in order to better understand how to improve solar incentive policies there.

Chapter 6 is the discussion of the solar PV installation possibility in Bangkok by comparing residential scale to large scale.

Chapter 7 presents the conclusion and the future work.

Chapter 2: Energy and Electricity in Thailand

This chapter presents the background of energy and electricity statistics in Thailand. The Section 2.1 and 2.2 introduce the current Thailand's energy and electricity status. The final part (Section 2.3) reviews the updated situation of solar energy in Thailand.

2.1 Energy Situation in Thailand

2.1.1 Primary Energy Supply

In 2013, the total primary energy supply was 5.3 quads per year. It can be categorized into four groups, which are domestic production, imports, exports, and stock change. The below Equation represents the meaning of primary energy supply.

$$\text{Primary Energy Supply} = \text{Domestic Production} + \text{Imports} - \text{Exports} + \text{Stock change} \quad (2.1)$$

Fig. 2.1 shows the diagram of Thailand's total energy supply in 2013. Fifty-eight percent of primary supply came from domestic production, and fossil fuels supply most of Thailand's energy. Natural gas has the largest proportion of energy supply (almost 50 percent), while alternative energy has a low proportion. Furthermore, in 2013, energy supply exported from Thailand was about 12 percent of total primary energy supply, but Thailand is a net energy importer of approximately 2.2 quads/yr. Most energy exports are petroleum products, such as gasoline, kerosene, diesel and fuel oil, and out-spec crude oils, and most energy imports are crude oil (Department of Alternative Energy Development and Efficiency, 2013).

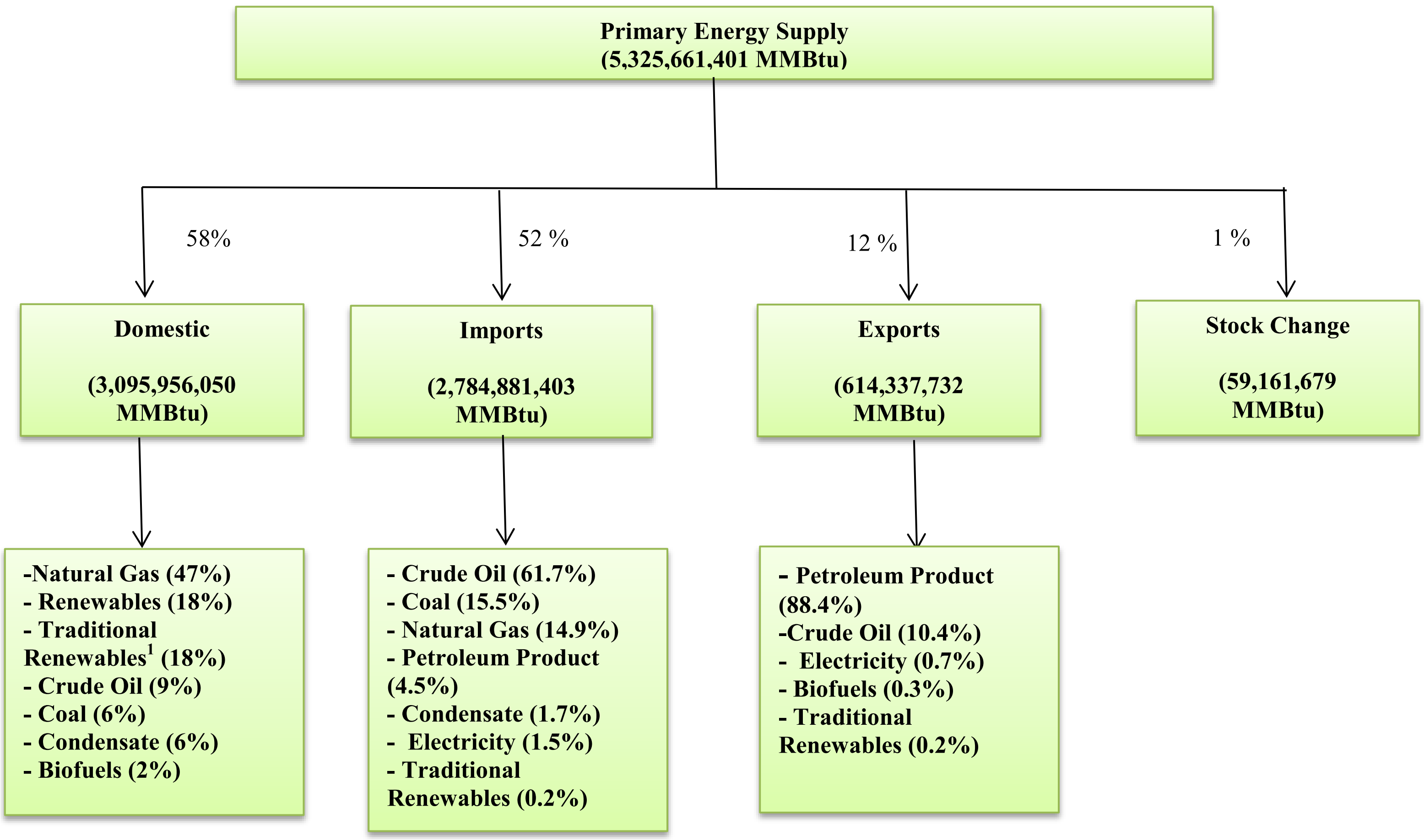

Figure 2.1: Thailand's Total Primary Energy Supply Diagram of 2013 (Adapted from Department of Alternative Energy Development and Efficiency, 2013)[1].

[1] Traditional Renewables are fuel wood, charcoal, paddy husk, and agricultural waste using in residential and industrial house hold

Thailand does not have enough domestic energy resources to supply the entire national energy demand. During the year 2013, energy supply imported to Thailand was about 2,784,881,403 MMBtu, which increased around 30 percent from 2012. Furthermore, around 50 percent of all energy supply for the whole country depends on imports (Fig. 2.1). It is crucial to strengthen energy security through increasing utilization of renewable energy as much as possible in the future to deal with this energy security problems (Department of Alternative Energy Development and Efficiency, 2012, Department of Alternative Energy Development and Efficiency, 2013).

2.1.2 Final Energy Consumption

Final energy consumption in 2013 was 2.9 quads, which is 56 percent of total primary energy supply. The remaining supply was for non-energy use (16 percent) and 28 percent was energy lost in energy transformations and conversions (petroleum refineries, natural gas processing, power plants and other conversion) (Department of Alternative Energy Development and Efficiency, 2013).

When considering final energy consumption, more than 60 percent (1.87 quads) of energy consumption in Thailand came from fossil fuels[2], while renewable energy[3], such as solar, biogas, and biomass shared about 7 percent (209,286,423 MMBtu). Thailand also used traditional renewable energy sources[4] that are not included in that 7 percent. Electricity[5], including off grid generation, is a significant part of the final energy

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2 Fossil fuels include coal, natural gas and petroleum product that are not related to electricity generation

3 For heat generation, not for electricity generation

4 Traditional Renewables are fuel wood, charcoal, paddy husk, and agricultural waste using in residential and industrial household

5 Both fossil fuel and renewable based electricity generation, including off grid generation

consumption since almost 20 percent (578,769,350 MMBtu) of final energy consumption was in the form of electricity (from both fossil fuel and renewables) (Fig 2.2).

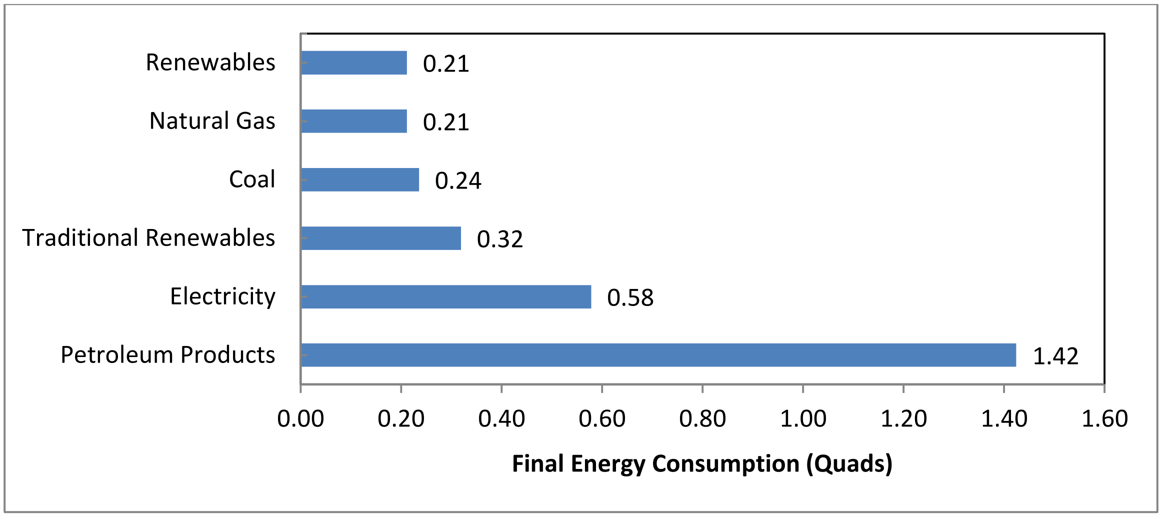

Figure 2.2: Final Energy Consumption 2013 (Adapted from Department of Alternative Energy Development and Efficiency, 2013).

Based on Fig. 2.3, most of the renewable energy in Thailand has been utilized as a heat source (133,943,310 MMBtu), four times more than for power generation (33,485,827 MMBtu). In addition, liquid biofuels (ethanol and biodiesel) account for 20 percent (41,857,286 MMBtu) of final renewable energy consumption in 2013 (Department of Alternative Energy Development and Efficiency, 2013).

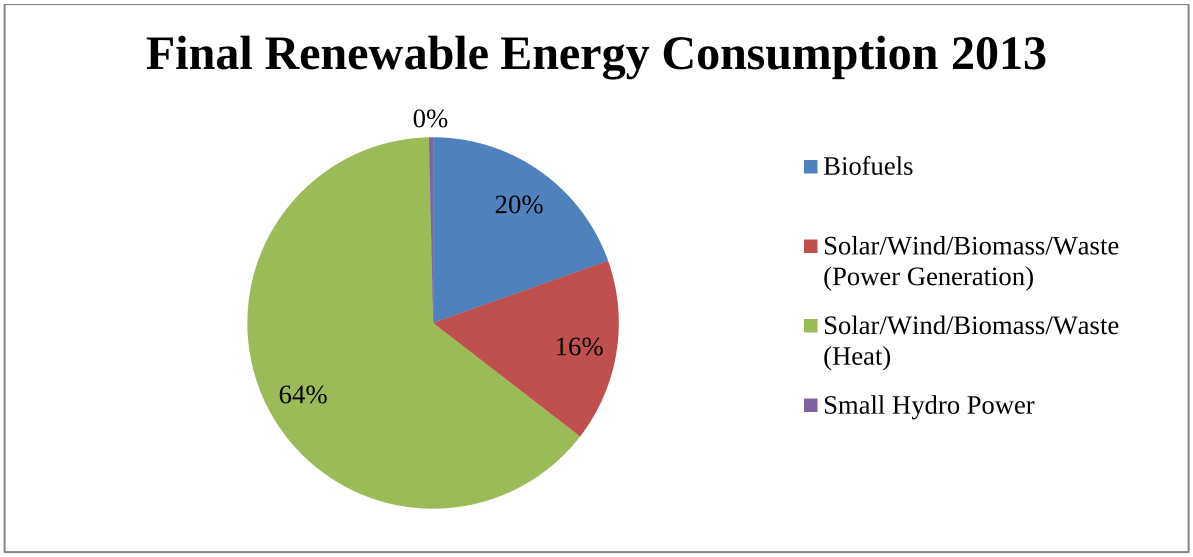

Figure 2.3: Final Renewable Energy Consumption 2013 (Adapted from Department of Alternative Energy Development and Efficiency 2013).

The industrial and transportation sectors were the top two energy users in Thailand (at 30 percent each) in 2013, while the remaining users were residential, commercial and agriculture (Fig 2.4). All coal supply was utilized in the industry sector that includes electricity, while petroleum products were mostly used for transportation. Natural gas is widely used in both industry and transportation sectors (Department of Alternative Energy Development and Efficiency, 2013). Modern (non-traditional) renewable energy is consumed only in the industry sector. Thus, this thesis asks why residential and commercial sectors in Thailand cannot also start using renewable energy.

Fig. 2.5 describes the estimated U.S. energy use in 2013 by economic sectors and types of fuel. In 2013, the U.S. consumed final energy consumption 97.4 quads, which is significantly more than Thailand. It is interesting that only 40 percent of total final energy consumption in the United States can be energy services, while the other 60 percent is classified as rejected energy (Lawrence Livermore National Laboratory, 2014).

The U.S. also has a high dependence on fossil fuels at more than 80 percent of primary energy. However, renewable energy in the U.S. is consumed at a higher percentage (approximately 10 percent) than in Thailand, while the other 10 percent of primary energy comes from nuclear energy. Biomass resources are the most important renewable energy resources, which shared around 4.5 percent of primary energy, whereas hydro, wind, solar and geothermal energy represent 2.6, 1.6, 0.3, and 0.2 percent of primary energy, respectively. (Lawrence Livermore National Laboratory, 2014).

Focusing on the U.S.'s final energy consumption by economic sectors, transportation and industry were the top energy users in 2013, just as in Thailand. Most petroleum products were used by transportation, whereas, coal was utilized mostly for electricity generation. Natural gas in the U.S. has been very useful due to its many purposes, such as for electricity generation, residential, commercial and industrial. One different energy consumption pattern between the U.S. and Thailand is a renewable use due to the fact that in Thailand, renewables are mainly used for heat generation rather than power supply. In the U.S., most renewables energy occurs in the form of electricity generation. If electricity generation in Thailand can be mixed like the United States has done, it will decrease the dependence of imported conventional energy in Thailand.

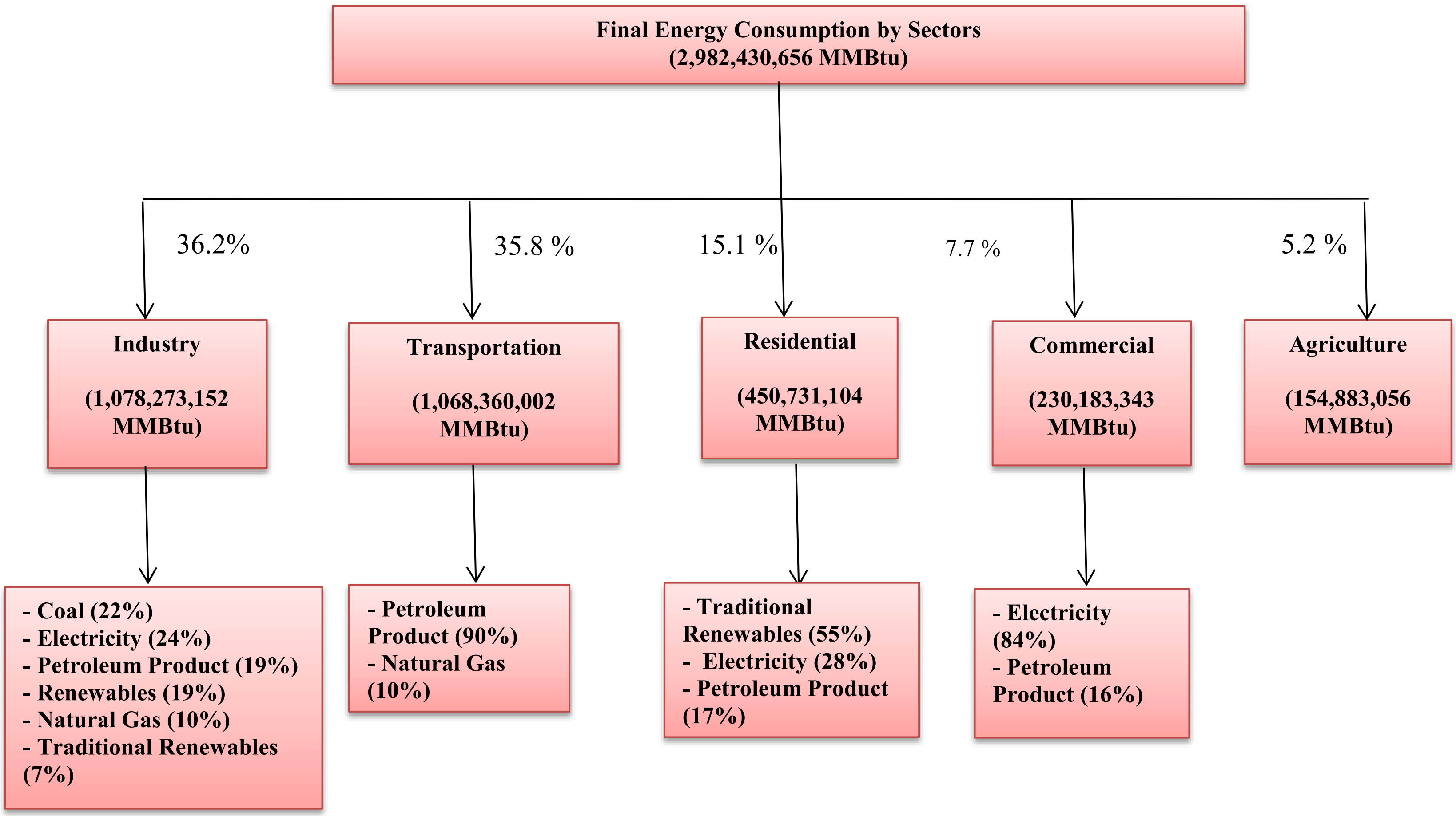

Figure 2.4: Thailand's Final Energy Consumption by Economic Sectors Diagram of 2013 (Adapted from Department of Alternative Energy Development and Efficiency, 2013).

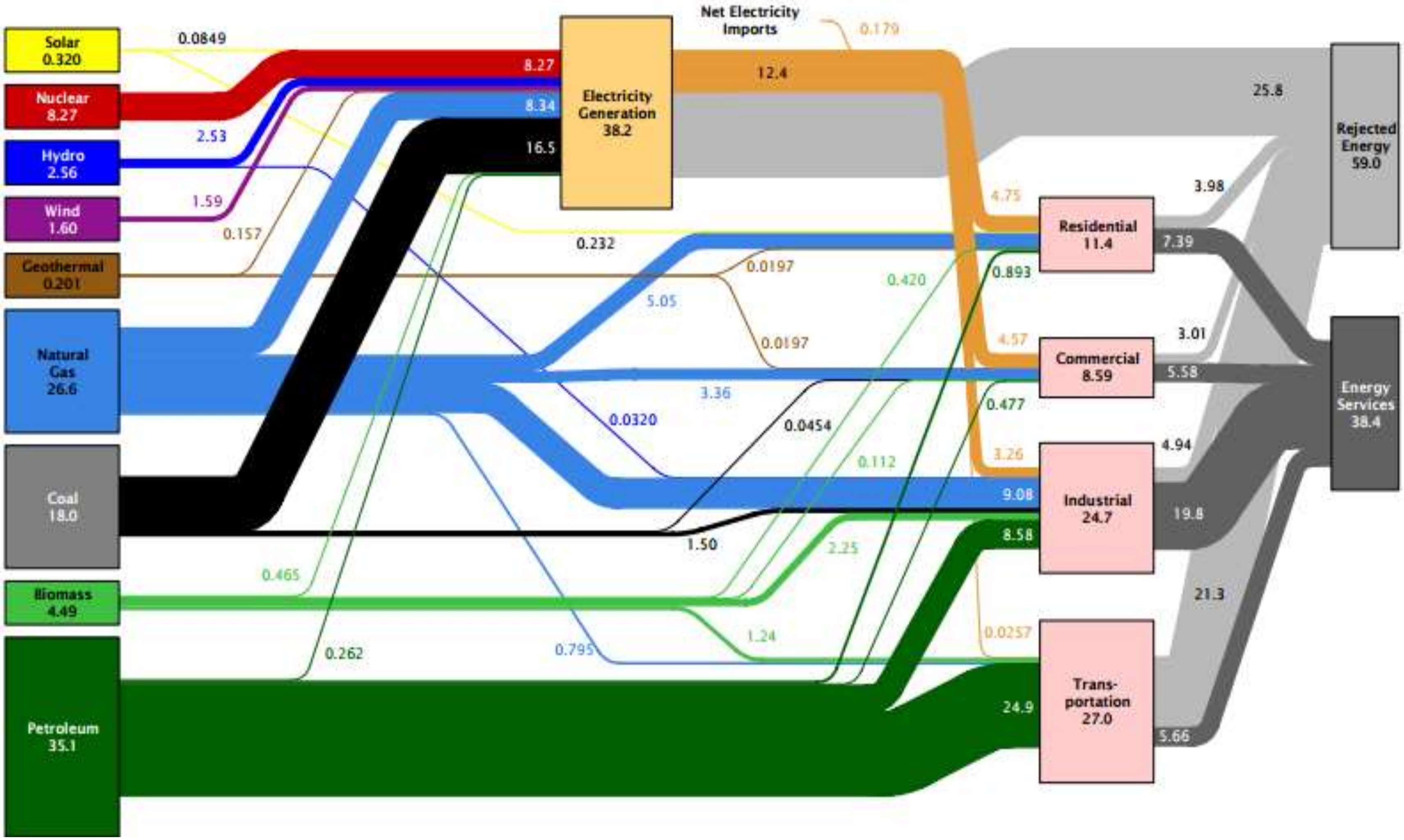

Figure 2.5: Estimated U.S. Energy Use in 2013 (Lawrence Livermore National Laboratory, 2014).

2.2 Electricity Situation in Thailand

2.2.1 Electricity Structure

Thailand's electricity structure is called the "Enhanced Single Buyer" (ESB) model evolving from a government monopoly to a semi-unbundled structure as illustrated in Fig. 2.6. The Electricity Generating Authority (EGAT) owns about 47 percent of generation assets and 100% of transmission assets. The other half of generation assets are developed by private companies, including Independent Power Producers (IPPs), Small Power Producers (SPPs), and Very Small Power Producers (VSPPs). IPPs and SPPs can produce and sell electricity to the high voltage transmission system owned by EGAT, while VSPPs cannot sell directly to EGAT. However, they are able to sell power through the two state owned distribution systems called the Metropolitan Electricity Authority (MEA) and the provincial Electricity Authority (PEA).

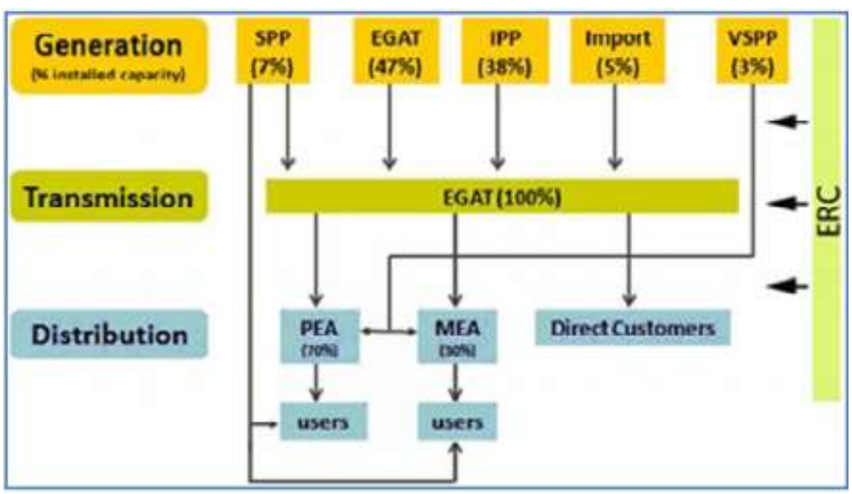

Figure 2.6: Electricity Structure in Thailand (Woradej, 2014).

MEA is responsible for the distribution, sales and services in Bangkok, Nonthaburi, and Samut Prakarn, whereas, PEA distributes to the rest of the country. In Thailand, any policies related to electric power and natural gas transmission are regulated by the Energy Regulatory Commission (ERC), not Ministry of Energy as for other energy-related policies (Ruangrong, 2012, Woradej, 2014).

2.2.2 Electricity Supply (Power Generation Mix)

Thailand is now facing an economic energy problem due to a high dependence on imported fossil fuels. These imports accounted for around 12 percent of GDP in Thailand. In addition, the trend of electricity demand continues increasing in the future. The relationship between power supply and peak demand is shown in Fig. 2.7. Thailand's peak demand of electricity increased from 14,918 in 2000 to 26,124 MW in 2013 (75 percent increase), while Thailand's electricity supply increased from 21,704 MW in 2000 to 32,185 MW in 2013 (52.7 percent increase) (Chaianong and Pharino, 2015 and Asian Institute of Technology, 2010).

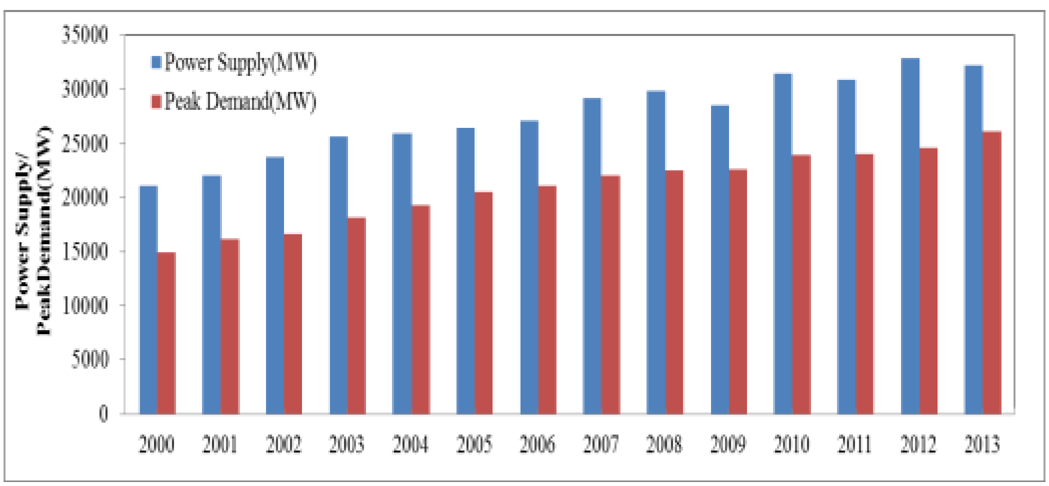

Figure 2.7: Thailand's Power Generation and Peak Demand during 2000-2013 (Adapted from Electricity Generating Authority of Thailand, 2013; Chaianong and Pharino, 2015).

Currently, looking at the power supply side, in 2014, more than 80 percent (155,219 GWh) of electricity comes from natural gas and coal. Also, Thailand has imported about 10 percent (10,960 GWh) of total power supply every year, whereas, renewable energy accounts for 3-5 percent (9,800 GWh) of the power generation mix that leads to an energy security problem due to the lack of diversity in power generation mix as well as the dependence on others for imported fossil fuels (Kasetsart University, 2012). Focusing on renewables, 61.3 percent is for biomass, 21.7 percent is for solar, and the other 17 percent is for biogas, wind, small hydro power, and waste energy (Department of Alternative Energy Development and Efficiency, 2013).

Considering the future trend of power generation mix, Thailand has an official power plan to use more renewables and nuclear instead of fossil fuels (see Fig. 2.8 and Section 2.3.1). However, they have been planning to import more electricity that might not be able to solve energy security problem since electricity supply in Thailand will still need to rely on neighboring countries.

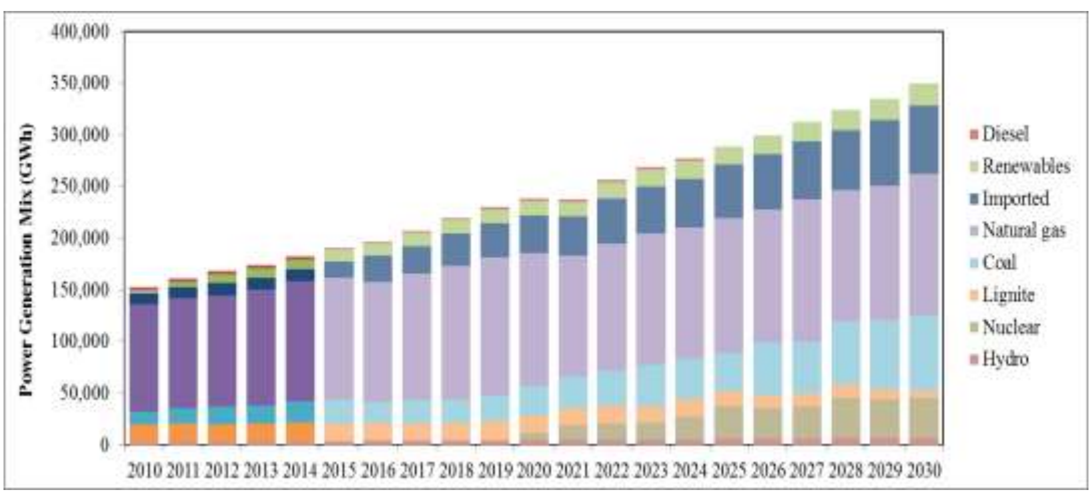

Figure 2.8: Thailand's Power Generation Mix during 2010-2030 (Adapted from Kasetsart University, 2012)

According to the U.S.' power generation mix in 2014, almost 70 percent (2,865 billion kWh) of power generation came from coal and natural gas, while nuclear was used approximately 20 percent (819 billion kWh). Renewables, like wind and hydro power, are another energy resource that helps prevent the U.S. from high dependence on non-renewable energy (Fig. 2.9). Moreover, the U.S. imports very little electricity to the country due to an adequate supply of domestic supply. In conclusion, the two major differences between Thailand and the U.S. energy supply are that the U.S. has a lower imported energy supply and a higher share of renewables and nuclear energy for power generation. Thus, Thailand needs to increase the diversity of generation mix in order to achieve green electricity (U.S. Energy Information Administration, 2015c).

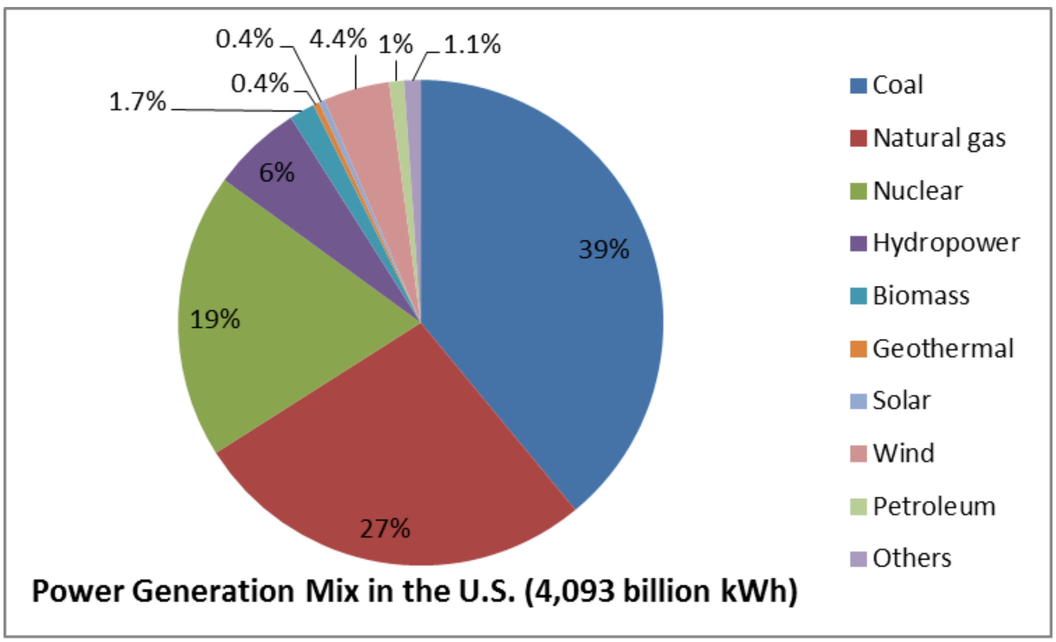

Figure 2.9: U.S.'s Power Generation Mix 2014

(Adapted from U.S. Energy Information Administration, 2015c)

2.2.3 Power Plant Dispatching

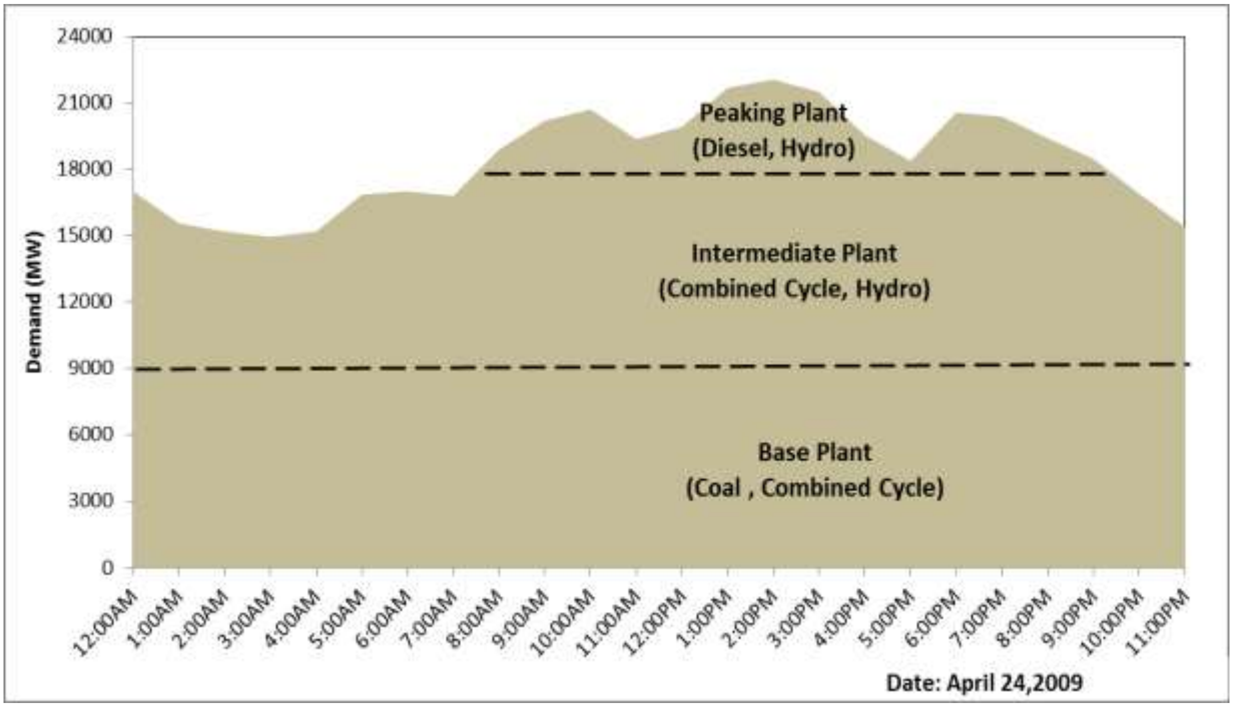

Figure 2.10: Thailand's Power Plant Dispatching

(Adapted from Energy Policy and Planning Office, 2011;

Energy Policy and Planning Office, 2013)

The variable operating cost of electric power generators is a key factor in determining which type of power plant needs to be operating to meet the marginal demand of electricity. Plants with the lowest variable operating costs are generally dispatched first, and plants with higher variable costs are brought on line to meet the increases demand.

Fig. 2.10 describes the dispatching diagram of power plants in Thailand for a typical operating day. The base load plants, which generally operate 24 hours per day year-round, appear on the bottom of peak demand curve. Base load power plants normally use the cheapest fuels and have the lowest marginal operating costs, such as coal. There are examples of base plant in Thailand called Mae Moh Power Plant (Coal) and Ja-na Power Plant (Combined Cycle using natural gas). Renewable power plants also have very low operating costs that can be dispatched first; however, their availability is limited by the temporal and intermittent patterns of the resource.

Intermediate plants run in the middle level of peak demand (between base load and peaking generators) by using combined cycle, single cycle natural gas, or diesel that leads to higher fuel costs. One example of an intermediate power plant is KEGCO Power Plant at the South of Thailand. Upward the top sides of peak demand curve are peaking plants, which mainly operate when hourly loads are at their highest by consuming diesel as a fuel or using hydro power plant, such as Bhumibhol Dam. In Thailand, the hydropower resources are difficult to be installed due to the environmental impact on the resource areas and they also have high operating costs as described in Chapter 4 (Fig. 4.1). Thus, hydroelectricity is unable to act as base load power generation.

2.2.4 Electricity Use by Sectors

Electricity consumption patterns depend on type of users, such as residential, commercial, and industrial. Residential consumers and small/specific businesses, such as hotels, consume electricity mostly in the evening, while peak demand of large scale users is in the afternoon. Thus, it is crucial for EGAT to dispatch power plants depending on demand and current type of power plant in Thailand

Fig 2.11 shows electric consumption by sector in Bangkok during the year of 2012. The average monthly electricity consumption was 4,114 GWh (Metropolitan Electricity Authority, 2013a). The details of electricity load will be further described in the next chapter.

More than 60 percent of electricity use in each month is related to residential scale and large general service that have been selected to study in this work.

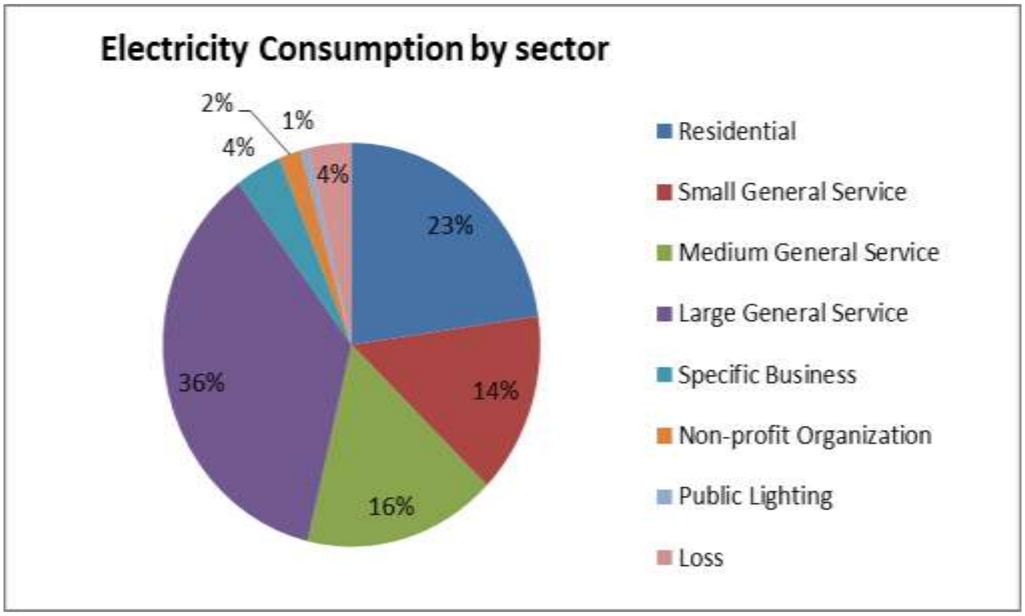

Figure 2.11: Electricity Consumption by sector in Bangkok 2012

(Adapted from Metropolitan Electricity Authority**,** 2013a)

2.2.5 Electricity Price Structure for Residential scale and Large scale[6] in Bangkok

Generally, in both residential and large scale, power tariff structure in Thailand can be calculated as in Equation 2.2 (Ruangrong, 2012).

$$\text{Power Tariff Structure} = \text{New Base Tariff} + F_t + \text{VAT} \qquad (2.2)$$

[6] Large-scale users means that a maximum 15-minute integrated demand is over 1,000 kilowatt, or the energy consumption for three average consecutive months through a single Watt-hour meter exceeds 250,000 kWh per month.

In Equation 2.2 the New Base Tariff consists of Initial Base Tariff, Base Fuel Adjustment Charge, and Public Service Obligation as further described in Sections 2.2.5.1-2.2.5.2; F_t is Fuel Adjustment Charge (at the given time); and VAT is Value-Added Tax (7%).

Fuel Adjustment Charge (F_t) is a mechanism for adjusting the power tariff that reflects the actual fuel supply cost that differs from the base cost at a given time. Normally, F_t will be adjusted every four months. It depends on EGAT fuel cost (27%), the power purchase cost (72%), and the impact of policy expense (1%), which is beyond the control of EGAT. According to Metropolitan Electricity Authority (2013b), current F_t is 0.015 US$/kWh[7]. Equation 2.3 describes the calculation of F_t (Ruangrong, 2012):

$$F_t = (FAC + AF) / EU \tag{2.3}$$

where, FAC is Fuel Adjustment Cost (the difference between the Estimation and the Base of fuel cost[8] for each period), AF is Accumulated Factor (the accumulated difference between the calculation-derived F_t and the $F_{t\ charged}$ in the previous round), and EU is Estimated Retail units in the present year round.

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[7] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

[8] Base Fuel Cost (BFC) is calculated from the fuel cost, power purchase cost and policy expense

2.2.5.1 Electricity Price for Residential scale

Residential-scale electricity price in Bangkok can be categorized into two groups: progressive rate tariff and Time of Use Tariff (TOU). The progressive rate is the tariff based on an actual unit consumed per month as shown in Tables 2.1 and 2.2.

Loads (kWh)	**Price per unit (US$/kWh)[9]**
1-15	0.058
16-25	0.078
36-100	0.097
101-150	0.100

Table 2.1: Progressive Rate Tariff for Residential Scale in Bangkok (Case I)
(Case I: Electric loads ≤ 150 kWh per month with a monthly fee of 0.254 US$ per month)
(Adapted from Metropolitan Electricity Authority, 2013c).

[9] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Loads (kWh)	Price per unit (US$/kWh)[10]
1-150	0.086
151-400	0.116
>401	0.122

Table 2.2: Progressive rate tariff for residential scale in Bangkok (Case II) (Case II: Electric loads ≥ 150 kWh per month with a monthly fee of 1.185 US$ per month) (Adapted from Metropolitan Electricity Authority, 2013c).

The main difference between Table 2.1 and 2.2 is the amount of electricity load used per month. If the monthly loads are less than 150 kWh, the customers would be charged as progressive rates in Table 2.1, while if the users consume electricity more than 150 kWh/month, they need to make a payment as shown in Table 2.2. In order to illustrate the payment calculation, Table 2.3 shows an example of electricity payment calculation for a residential customer in Bangkok by assuming the total electricity use is 350 kWh per month.

[10] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Details	Electricity Price (US$)[11]
Part I: Electricity Rate	
1-150 kWh Load (@ 0.086 US$/kWh)	12.90
151-350 kWh Load (@ 0.116 US$/kWh)	23.20
Part II: Monthly fee	
Monthly fee (1.18 US$/month)	1.18
Subtotal	*37.28*
Part III: Ft Charge	
Ft Charge (0.015 US$/kWh)	5.25
Part IV: VAT	
VAT (7%)	2.98
Total Monthly Payment	**45.51**

Table 2.3: An Example of Progressive Rate Tariff for Residential Scale in Bangkok (Assuming that electricity use is 350 kWh)

Apart from the progressive rate tariff, the TOU is another way to calculate monthly electricity payment as described in Table 2.4. The main purpose of TOU is to encourage customers to use electricity during off-peak periods. To illustrate the calculation of TOU method, Table 2.5 shows an example of monthly electricity payment for 350 kWh/month by residential users in Bangkok by assuming the on-peak electricity use is 100 kWh and the off-peak electricity use 250 kWh under TOU method and the

[11] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

voltage level is less than 12 kV. From Table 2.5, one can see that the electricity payment using TOU method is less than the progressive rate procedure (in Table 2.3) because as stated earlier, most of residents in Bangkok usually consume the electricity during off-peak period.

Voltage Level[12] (kV)	**On Peak Price per unit (US$/kWh)[13]**	**Off Peak Price per unit (US$/kWh)[13]**	**Monthly fee (US$/kWh)[13]**
12-24	0.135	0.064	9.237
<12	0.156	0.069	1.185

Table 2.4: Time of Use Tariff (TOU) for Residential Scale in Bangkok
(On Peak: 9am-10pm Monday to Friday and Off Peak: 10pm-9am Monday to Friday, 12am-12pm Saturday to Sunday)
(Adapted from Metropolitan Electricity Authority, 2013c).

[12] Refers to the voltage of the electricity delivered to the transformer outside the homes
[13] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Details	Electricity Price (US$)[14]
Part I: Electricity Rate	
100 kWh On Peak (@0.156 US$/kWh)	15.60
250 kWh Off Peak (@0.069 US$/kWh)	17.25
Part II: Monthly fee	
Monthly fee (1.18 US$/month)	1.18
Subtotal	*34.03*
Part III: Ft Charge	
Ft Charge (0.015 US$/kWh)	5.25
Part IV: VAT	
VAT (7%)	2.75
Total Monthly Payment	**42.03**

Table 2.5: An Example of TOU method for Residential Scale in Bangkok

(Assuming that the on-peak electricity use is 100 kWh, the off-peak electricity use is 250 kWh, and electricity voltage level is less than 12 kV)

[14] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

2.2.5.2 Electricity Price for Large scale

Based on Metropolitan Electricity Authority (2013c), large scale price in Bangkok can be classified into two groups: Time of Day Tariff (TOD) and Time of Use Tariff (TOU).

Time of Day Tariff (TOD) is the tariff based on demand peak, demand partial peak, and demand off peak in each day as shown in Table 2.6. The Time of Use Tariff (TOU) is the tariff depending on time of peak or off peak in each individual day as described in Table 2.7. The electricity billing demand used for both Tables 2.6 and 2.7 is defined as the maximum 15-minute integrated demand during an On-Peak and Partial-Peak period over the monthly billing period. Furthermore, in order to elucidate the electricity payment of large-scale consumers, Table 2.8 and 2.9 shows the examples of electricity payment calculation of both TOD and TOU methods, respectively.

Voltage (kV)	Electricity Demand Rate (US$/kW) [15]			Electricity Price (US$/kWh) [15]	Monthly Fee (US$)[15]
	On Peak	Partial Peak	Off Peak		
>69	6.64	0.88	0	0.078	9.24
12-24	8.43	1.74	0	0.079	9.24
<12	9.84	2.02	0	0.08	9.24

Table 2.6: Time of Demand Tariff (TOD) for Large Scale in Bangkok

(On Peak: 6:30-9pm Monday to Sunday, Partial Peak: 8am-6:30pm Monday to Sunday (only the surplus from on-peak demand), and Off Peak: 9:30pm-8 am Monday to Sunday)

(Adapted from Metropolitan Electricity Authority, 2013c).

[15] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Voltage (kV)	**Electricity Demand Rate (US$/kW)** [16]		**Electricity Price (US$/kWh)** [16]		**Monthly Fee (US$)**[16]
	On Peak	Off Peak	On Peak	Off Peak	
>69	2.19	0	0.106	0.063	9.24
12-24	3.93	0	0.108	0.064	9.24
<12	6.21	0	0.113	0.065	9.24

Table 2.7: Time of Use Tariff (TOU) for Large Scale in Bangkok

(On Peak: 9am-10pm Monday to Friday and Off Peak: 10pm-9am Monday to Friday, 12am-12pm Saturday to Sunday)

(Adapted from Metropolitan Electricity Authority, 2013c).

[16] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Details	Electricity Price (US$)[17]
Part I: Electricity Demand Rate	
500 kW On Peak (9.84 US$/kW)	4,920
1,000 kW Partial Peak (2.02 US$/kW)	1,010
500 kW Off Peak (0 US$/kW)	0
Part II: Electricity Price	
500,000 kWh (0.08 US$/kW)	40,000
Part III: Monthly fee	
Monthly fee (9.24 US$/month)	9.24
Subtotal	*45,939.24*
Part II: Ft Charge	
Ft Charge (0.015 US$/kWh)	7,500
Part III: VAT	
VAT (7%)	3,740.75
Total Monthly Payment	**57,179.99**

Table 2.8: An Example of TOD for Large Scale in Bangkok

(Assuming that electricity demand is 500 kW of on-peak period, 1,000 kW of partial-peak period, and 500 kW of off-peak period; electricity use is 500,000 kWh per month, and electricity voltage is less than 12 kV)

[17] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

Details	Electricity Price (US$)[18]
Part I: Electricity Demand Rate	
1,500 kW On Peak (6.21 US$/kW)	9,315
500 kW Off Peak (0 US$/kW)	0
Part II: Electricity Price	
350,000 kWh (0.113 US$/kW)	39,550
150,000 kWh (0.065 US$/kW)	9,750
Part III: Monthly fee	
Monthly fee (9.24 US$/month)	9.24
Subtotal	*58,624.24*
Part II: Ft Charge	
Ft Charge (0.015 US$/kWh)	7,500
Part III: VAT	
VAT (7%)	4,628.70
Total Monthly Payment	**70,752.94**

Table 2.9: An Example of TOU method for Large Scale in Bangkok

(Assuming that electricity demand is 1,500 kW of on-peak period and 500 kW of off-peak period; electricity use is 350,000 kWh for on-peak period and 150,000 kWh for off-peak period, and electricity voltage is less than 12 kV)

[18] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

2.3 Solar Energy Situation in Thailand

2.3.1 Thailand Power Development Plan 2012-2030

The Thailand Power Development Plan 2010-2030 (PDP 2010) was approved by the Nation Energy Policy Council (NEPC) on March 12, 2011. The objective of this plan is to focus on the security and adequacy of the power system along with aspects of environmental concern, energy efficiency, and renewable energy promotion (Energy Policy and Planning Office, 2012).

The key assumptions for PDP2010 (Revision 3) includes:

- The power demand forecast (load forecast) needs to contain energy saving and energy efficiency promotions;
- Thailand should have the proper level of reserve margin (not less than 15 percent of peak power demand). In case if natural gas supply is cut off, the reserve margin should be higher than 20 percent of peak demand;
- The future of electricity generation mix needs fuel diversification in order to reduce natural gas dependency;
- Electricity should be generated from renewable energy by greater than 5 percent;
- Electricity acquiring from nuclear power plant should be not greater than 5 percent of total capacity;
- Clean coal is necessary to decrease greenhouse gas emission from coal-fired power plant;
- Thailand should not purchase power from neighboring countries greater than 15 percent;
- It is important to promote cogeneration system;
- The target of carbon dioxide emission should be not higher than that of the previous revision of PDP2010.

In order to achieve the PDP 2010, total capacity is projected to be about 70,686 MW by adding 55,310 MW during 2012-2030 that can be classified by power plant types as the below table. It is noticeable that renewable energy power plants are necessary for Thailand to help reduce peak demand due to continuous electricity demand's growth.

Type of Power Plant	**Adding Capacity (MW)**
Renewable Energy Power Plants (from domestic and neighboring countries)	14,580
Cogeneration	6,476
Combined Cycle Natural Gas Power Plants	25,451
Coal-fired Power Plants	4,400
Nuclear Power Plants	2,000
Gas Turbine Power Plants	750
Power Purchase from Neighboring Countries	1473
Total	**55,130**

Table 2.10: Adding Power Plant Capacity during 2012-2030 (Adapted from Energy Policy and Planning Office, 2012)

2.3.2 The Alternative Energy Development Plan (AEDP 2012-2021)

According to the Power Development Plan, the Alternative Energy Development Plan was enacted by Ministry of Energy in Thailand in order to increase renewable energy consumption to be 25 percent of the total energy consumption by 2021 using the following strategies (Sutabutr, 2012):

- Promoting community participation in alternative energy;
- Encouraging private sector by incentives and policies;
- Adjusting law and regulations to favor alternative energy development;
- Improving infrastructure, such as the smart grid;
- Supporting public relation;
- Sponsoring Research and Development (R&D) for renewable energy industries.

The objectives of this plan include (Sutabutr, 2012):

- To develop alternative energy and decrease fossil fuels dependency;
- To fortify national energy security;
- To create zero-waste integrated complex;
- To support renewable energy production in the country;
- To research and develop alternative energy technology.

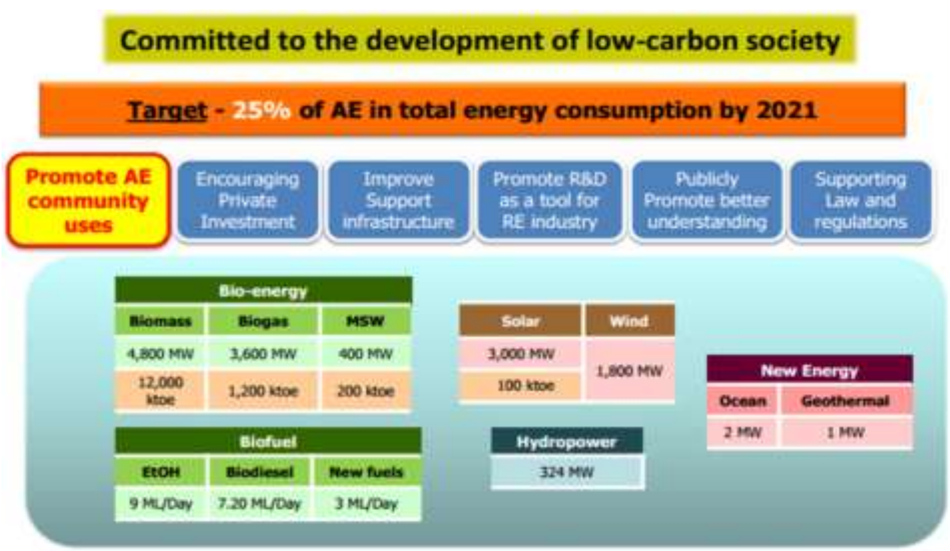
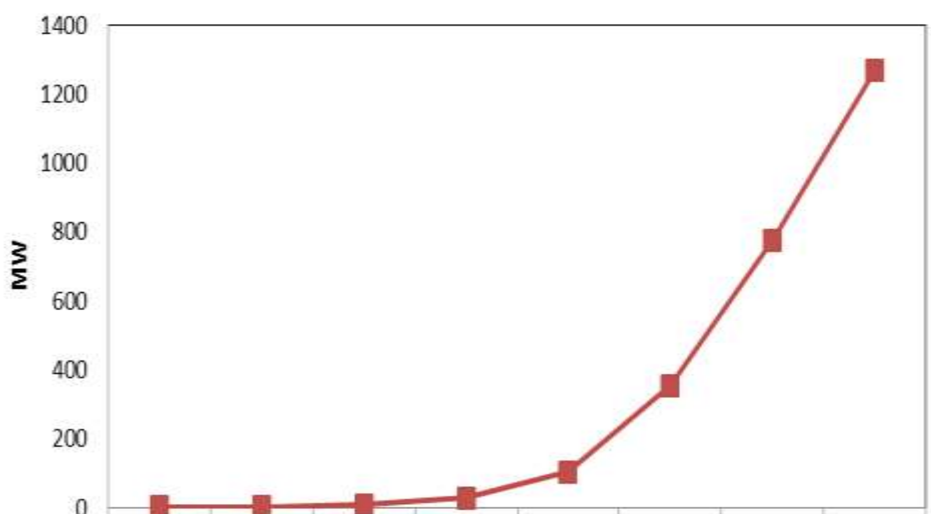


Figure 2.12: Development of Green Energy towards Low-carbon Society

(Sutabutr, 2013)

Fig. 2.12 represents the AEDP target of each type of renewable energy including bio-energy, biofuel, solar, wind, hydropower, ocean and geothermal. Focusing on solar energy, in 2013, the AEDP target of solar power generation at the year end in 2021 is 3,000 MW (Sutabutr, 2013). However, based on the rapid growth of solar installation as shown in Fig. 2.13, the National Energy Policy Council (NEPC) decided to move the target forward from 2021 to the end of 2015 and increase a total target from 3,000 MW to 3,800 MW (2,800 MW solar farms, 800 MW solar farms on government land and agricultural cooperatives, and 200 MW solar PV rooftop).



	2007	2008	2009	2010	2011	2012	2013	2014
Installed Solar Capacity (MW)	1	2	8	26	103	354	776	1269

Figure 2.13: On-Grid Solar Installation Capacity during 2007-2014

(Adapted from Tongsopit, 2015)

In order to meet the ADEP target, solar development and promotion strategies are set as follows:

- Promoting small solar systems for the household and community, such as industrial rooftop, housing/condominium rooftop, and government building rooftop;
- Setting up financial incentives to encourage private investment to install solar energy;
- Amending law and regulations that obstruct solar energy development, such as adjusting the Industrial Act 1992;
- Improving electricity infrastructure (both transmission and distribution);
- Supporting Research and Development on solar energy technology.

2.3.3 Current Status of Solar Energy in Thailand

The installed capacity of solar PV energy in Thailand, which accounts for almost 90 percent of total solar energy generated (Chaianong and Pharino, 2015), is shown in Table 2.11-2.13.

Solar Program	**Status of Solar Program**	**Number of Projects**	**Capacity (MW)**	**Target (MW)**
Solar Farm	COD achieved	196	1387.10	2,800
	PPA-signed	5	99.72	
	PPA-accepted	26	148.67	
	PPA-applied for and recently approved	172	989.68	
	Total	399	2,605.17	
Solar Farms on government land and agricultural cooperatives		0	0	800

Table 2.11: Current Solar Farm installed in Thailand as of May 2015 (Adapted from Federal Ministry for Economic Affairs and Energy and Energy Research Institute, 2015)

Solar Program	Status of Solar Program	Number of Projects	Capacity (MW)	Target (MW)
Residential Rooftop	COD achieved	248	1.47	100
	PPA-signed	2,486	19.50	
	PPA-accepted	308	2.29	
	Total	3,042	23.26	

Table 2.12: Current Residential Solar Rooftop installed in Thailand as of May 2015 (Adapted from Federal Ministry for Economic Affairs and Energy and Energy Research Institute, 2015)

Solar Program	Status of Solar Program	Number of Projects	Capacity (MW)	Target (MW)
Commercial Rooftop	COD achieved	84	49.19	100
	PPA-signed	109	48.88	
	PPA-accepted	27	7.69	
	Total	220	107.76	

Table 2.13: Current Commercial Solar Rooftop installed in Thailand as of May 2015 (Adapted from Federal Ministry for Economic Affairs and Energy and Energy Research Institute, 2015)

Based on Table 2.11, a total 1,615.50 MW of solar farms, mostly located in the Northeast of Thailand, were constructed by May 2015, which consists of 1,387.10 MW of Commercial Operation Date (COD) achieved, 99.72 MW of Power Purchase Agreement (PPA) signed, and 148.67 MW of PPA accepted. As for the remaining 989.676 MW (172 projects) were already accepted to receive PPAs in May and will be granted a Feed-in Tariff (FiT) of 0.17 US$/kWh[19] for 25 years. Due to the good progress and the small difference between the target (2,800 MW) and the current total installed capacity (about 2,600 MW), it is possible to reach the target within the deadline.

A government and agricultural cooperatives program for solar farms was introduced in August 2014 with an overall target of 800 MW to encourage governmental sector and agricultural cooperatives to install solar farms (each with a capacity of 5 MW or less). These solar farms will also be granted a FiT at the same rate as normal solar farms (0.17 US$/kWh[19]) over 25 years. The COD must not be later than June 30, 2016. Unfortunately, as of May 2015, there are not any farms installed in this program due to the fact that the purchase of power has not been announced yet. The committee is still working on some technical issues related to transmission line capability and on governmental restriction issues.

The solar rooftop target for in Thailand was set in 2013 at 200 MW (100 MW for residential scale and another 100 MW for commercial scale). Based on Tables 2.12 and 2.13, residential-scale solar rooftop has reached approximately 23 MW, and thus more installations are needed to meet the target; however, commercial-scale solar rooftop installations have already achieved the target. The National Energy Policy Council (NEPC) also announced the recent FiT for solar rooftop in order to fulfil the target of 100

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[19] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

MW of residential scale (Table 2.14). This rooftop incentive for selling electricity to the grid will also apply for 25 years with the COD that must not be later than December 31, 2015.

Capacity (MW)	**FiT (US$/kWh)[20]**
Residential Rooftop (0-10 kW)	0.20
Commercial Rooftop (10-250 kW)	0.19
Large Commercial Rooftop (250-1,000 kW)	0.18

Table 2.14: Current Feed-in Tariff for Solar Rooftop Installation (Adapted from Federal Ministry for Economic Affairs and Energy, and Energy Research Institute, 2015)

As discussed above, approximately 2,700 MW of solar PV installations (more than 95 percent) are centralized utility scale and commercial installations, while solar PV installation for residential rooftop scale is about 23 MW (Tongsopit, 2015). Distributed energy, like residential solar rooftop, seems to have high potential to enhance domestic energy security in Thailand, especially in Bangkok since it is the city with the highest power demand in the country. Rooftop PV is also important for remote areas in Thailand because many homes in these areas do not have electricity grid connection. Therefore, if

[20] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

the solar panels can be distributed to these remote areas, it can significantly increase the quality of life for the rural residents.

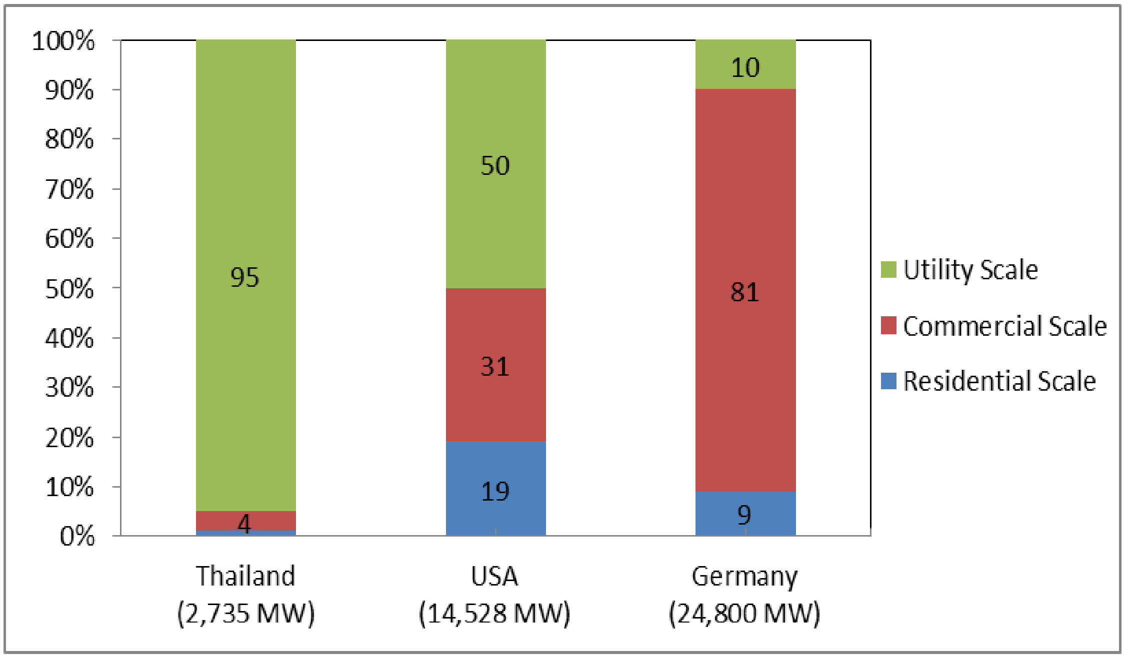

Figure 2.14: Comparison of On-Grid Solar Installation by System Sizes in Different Countries

*Notes: Status at various dates--Thailand (2015); USA (2014); Germany (2011)

(Adapted from Tongsopit, 2015)

Fig 2.14 shows the comparison of solar installation by different installation types among Thailand, the U.S., and Germany. The capacity of solar PV installed in Thailand is less than the U.S. and Germany around 5 and 9 times respectively. Based on international experiences, both the U.S. and Germany have mainly installed solar PV in utility and commercial scale (greater than 80 percent of total installations). However, solar installations in Thailand are even more dominated by utility scale projects at 95 percent.

Thailand's installed solar PV rooftop at residential scale accounts for only 1 percent of total solar installations.

Thus, it is necessary to understand why Thailand cannot widely adopt decentralized model of solar energy as many countries have done. In this thesis, as stated, the technical, economic, and policy aspects have been investigated to answer this question. Also, some policy suggestions and the discussion of possibility of solar PV installation are already made in order to increase the opportunity of solar rooftop in residential scale of Bangkok.

Chapter 3: Technical Analysis

The primary aim of this chapter is to represent the technical analysis of residential-scale solar PV installation compared to the large-scale PV[1] in Bangkok. The first part (Section 3.1) of this chapter introduces Bangkok's solar irradiance and electric load pattern. The second part (Section 3.2) reviews the methodology that has been used in this work. In section 3.3, all results are reported to comprehend the trend of load pattern and daily insolation of both scales and also provide some barriers related to technical issues. Furthermore, in Section 3.4 presents the technical barriers that slow the implementation rate of residential solar PV. Finally, the last part (Section 3.5) summarizes the key issues of the technical analysis.

3.1 Introduction

3.1.1 Solar Irradiance in Bangkok

Fig 3.1 shows the daily solar irradiance map of Thailand, including Bangkok located in the Central area. The average solar radiation of Thailand is approximately 5.2 kWh/m^2/day (Electricity Generating Authority of Thailand, 1999). It is observed that the areas that receive high radiation compared to other regions are the Northeast, partly the central area and the upper east coast of the South, whereas, the low radiation areas are located in the North, most parts of the South and eastern part of the Central area.

Thailand has three seasons in a year, which are summer (February-May), rainy (June-October), and winter (November-January). The seasonal variation evidently affects solar radiation in Thailand. During the middle of October till January (winter season), sun radiation is high in the North, Northeast and the Central area, while it is quite low in the

[1] Large-scale PV means the installed capacity is between 250-1,000 kilowatt-peak (kWp)

South. The main reason is that the Northeast monsoon brings cold and dry air from Asia continent to Thailand, causing clear skies in all mentioned areas. However, when the Northeast Monsoon comes across the Gulf of Thailand, it brings moisture and humid air to the South, causing rainfall and cloudy skies (lower in sun radiation). When considering summer season in Thailand, from February to April, it is a sunny period, with high sun insolation all over the country. Then, during May through October, the Southwest monsoon starts from the Andaman Sea creating rainy and cloudy conditions in most of the country (Janjai, 2010).

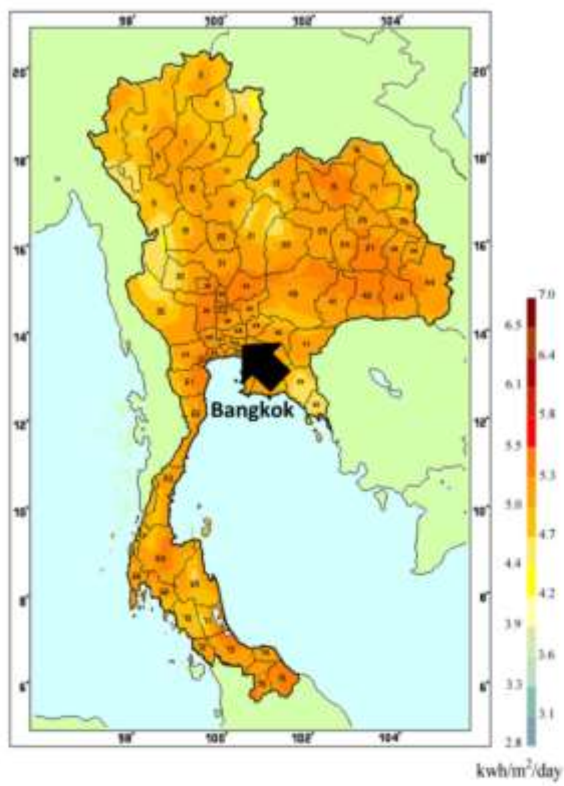

Figure 3.1: Daily Solar Irradiance Map of Thailand

(Adapted from Electricity Generating Authority of Thailand, 1999).

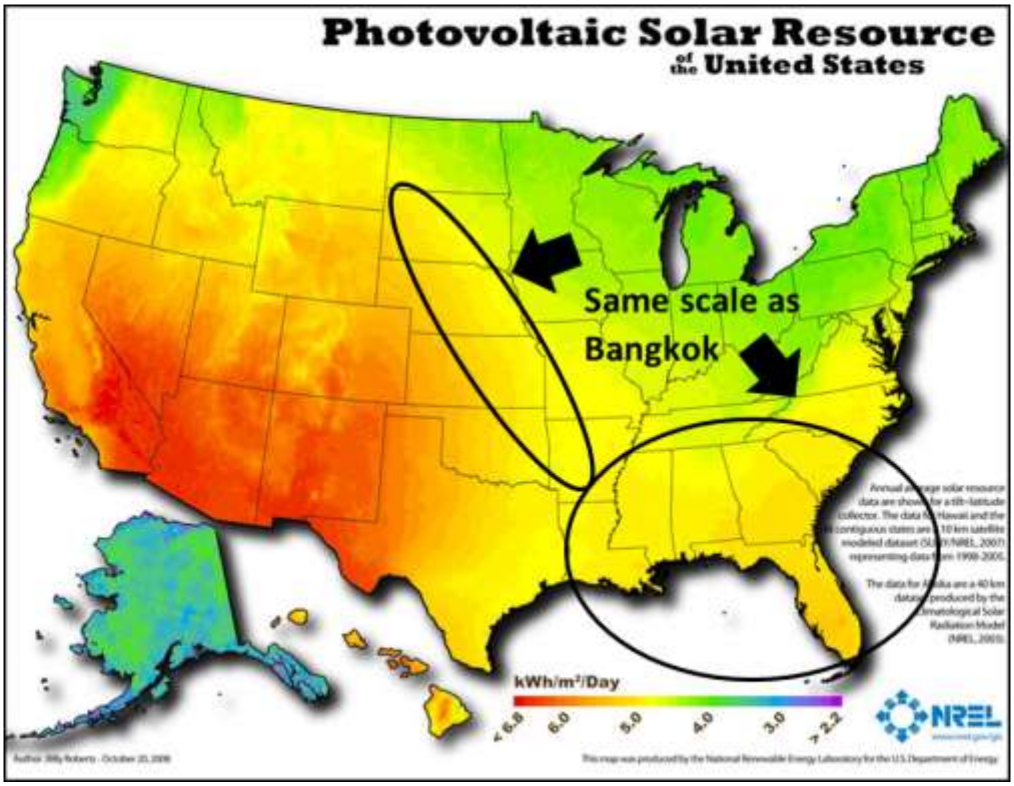

Figure 3.2: Daily Solar Irradiance Map of the U.S.

(Adapted from National Renewable Energy Laboratory, 2008).

Fig. 3.2 represents daily solar irradiance map of the U.S. It is remarkable that solar radiation in the U.S. varies more across the country with an average about 4.9 kWh/m^2/day. Sun insolation has lower intensity in the North, while in the Southwest, most states, such as California and Nevada, have higher intensity of solar radiation.

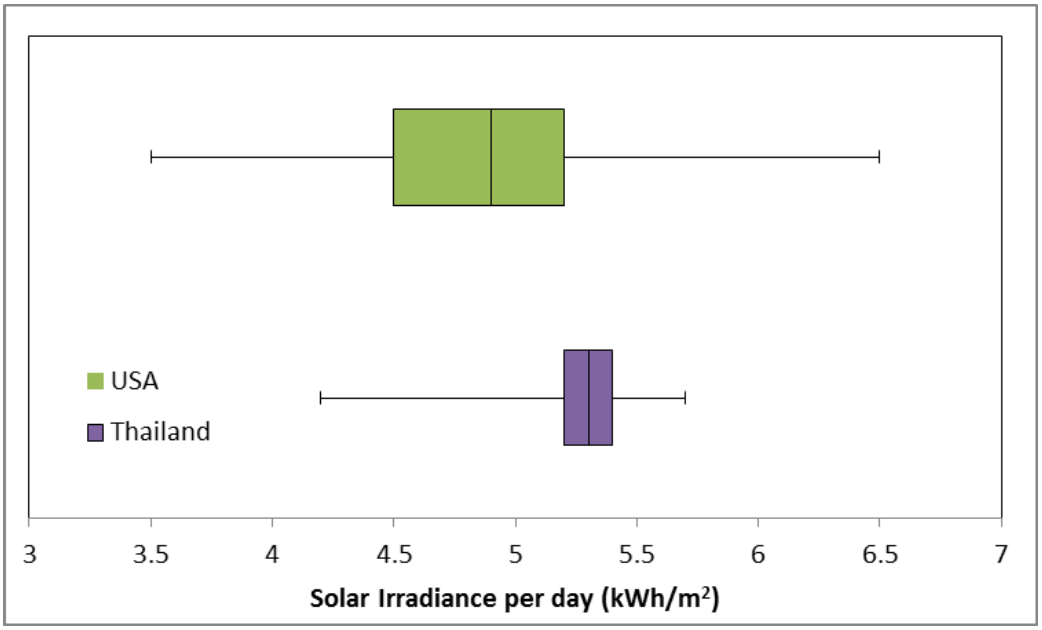

Figure 3.3: Solar Irradiance Comparison between Thailand and the U.S.*

(Adapted from Electricity Generating Authority of Thailand, 1999 and National Renewable Energy Laboratory, 1990).

*Note: Whiskers represent the minimum and maximum values with the edges of the boxes representing 25% to 75% range.

Comparing between Thailand and the U.S. (Fig. 3.3), Thailand has a higher average of solar radiation than the U.S. However, due to the much smaller size of Thailand, it has a lower variation of solar intensity. This is a big difference between Thailand and the U.S.'s solar irradiance; because the U.S. is large in area. It has a wider range of solar intensity across the country.

When focusing on Bangkok, it is located in the Central area of Thailand that has the same solar intensity (approximately 5 kWh/m^2/day) as in the Southeast and some parts of Midwest of the U.S. (Fig. 3.2). The sun radiation is high in summer (February – April). In winter and rainy season, the sun radiation is affected by the Northeast and the

Southwest monsoon respectively caused lower solar irradiance across the area as shown in Fig. 3.4. Looking deeply into hourly solar irradiance in Bangkok (Fig. 3.5), the peak of sun intensity is from 9am-3pm. This period of day can be a good time for generating electricity from solar PV in Bangkok. In the next section, the electricity load pattern is discussed to compare to the insolation

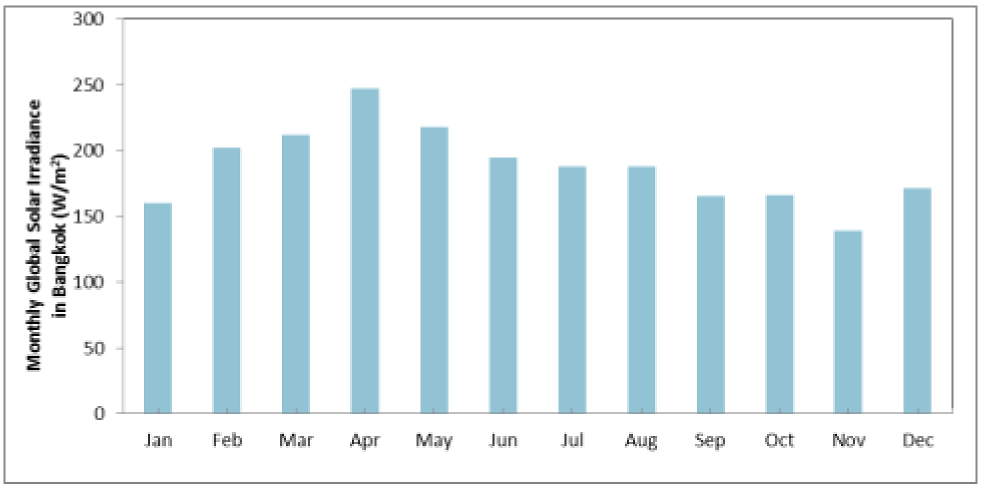

Figure 3.4: Monthly Solar Irradiance in Bangkok (Averaged over each month) (Adapted from Solar Energy Development, 2012).

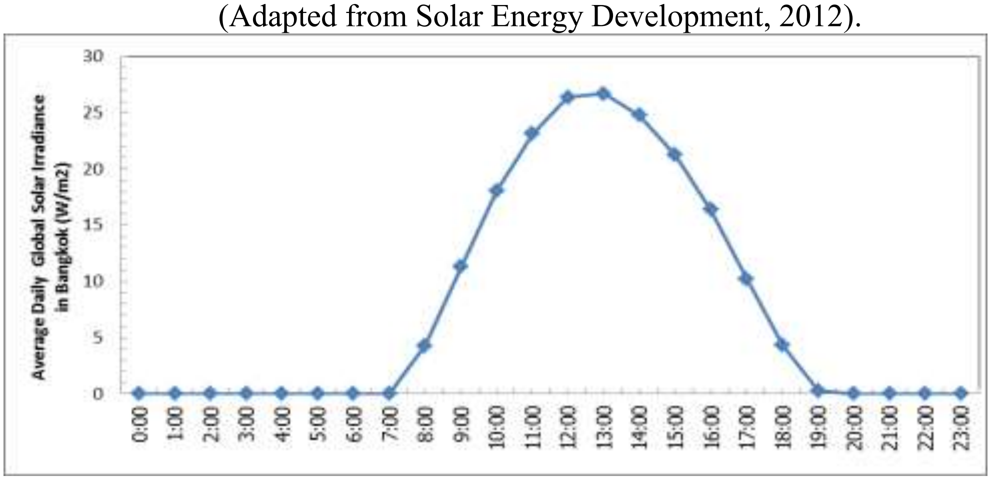

Figure 3.5: Hourly Solar Irradiance in Bangkok (Averaged over each day) (Adapted from Solar Energy Development, 2012).

3.1.2 Load Pattern

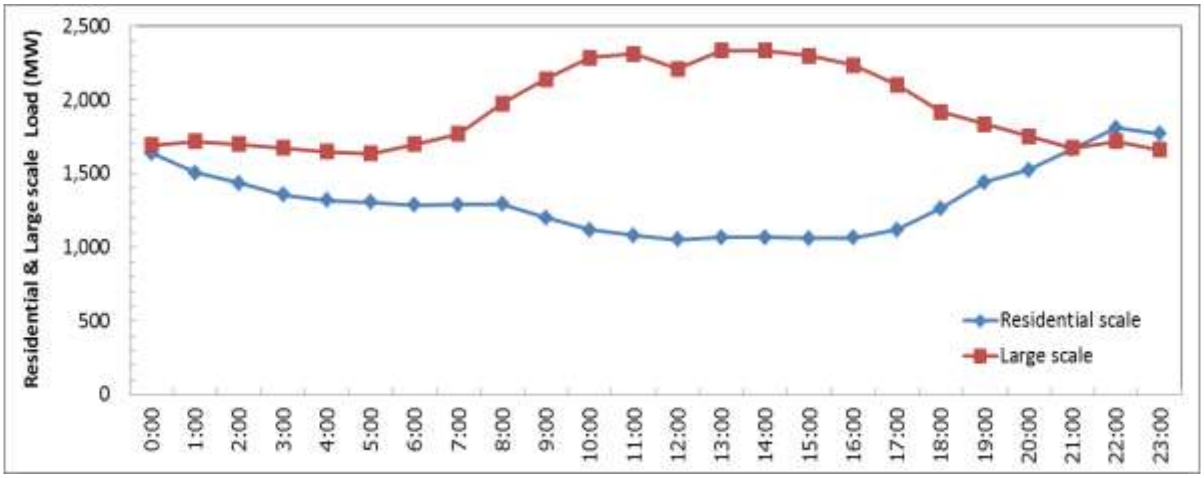

Figure 3.6: Residential-scale and Large-scale Load[2] in Bangkok (Average day, 2012) (Adapted from Metropolitan Electricity Authority, 2012).

The large-scale consumers, such as manufacturing and hotel, normally, consume electricity more than the households. According to Metropolitan Electricity Authority (2012), the average loads per household per month are around 400 kWh, while the monthly average loads for large scale are 600,000 kWh. Figure 3.6 shows residential-scale and large-scale load of an average day in 2012 in Bangkok. The electricity peak load of the large scale in Bangkok is around 2,300 GW, while residential scale's peak load is at 1,300 GW. Additionally, the electricity load pattern of residential scale and large scale are completely different. For households, the peak electricity demand in each day is at night (around 9 pm till midnight) due to the fact that most residents in Bangkok usually work all day and only return home in the evening. Large scale users consume electricity much more during daytime since industrial activities are running at that time

[2] Large-scale load means the average peak demand is more than 1,000 kW in 15 minutes, or monthly electricity consumption is more than 250,000 kWh in 3 consecutive months

period. When considering each season in Thailand, electricity demand is higher in summer due to the air-conditioners. However, the peak load does not significantly increase at that time as occurred in other countries, including the U.S. One reason is that some Bangkok residents might not be able to afford the higher electricity bill that results from increased consumption due to the air conditioner.

Furthermore, there are some differences between weekday and weekend load pattern of both residential and large-scale as shown in Fig. 3.7 and 3.8., respectively According to Fig. 3.7 for residential scale, the load pattern of both weekday and weekend is quite the same as it peaks at night. But, weekend load is more than weekday load especially at noon because most residents stay at home during weekend. In contrast, when compared to the large scale (Fig. 3.8), all days in the week have a similar pattern of electricity use, but weekday load of large scale is more than weekend due to the fact that offices, commercial buildings, and industry operate more during the weekdays.

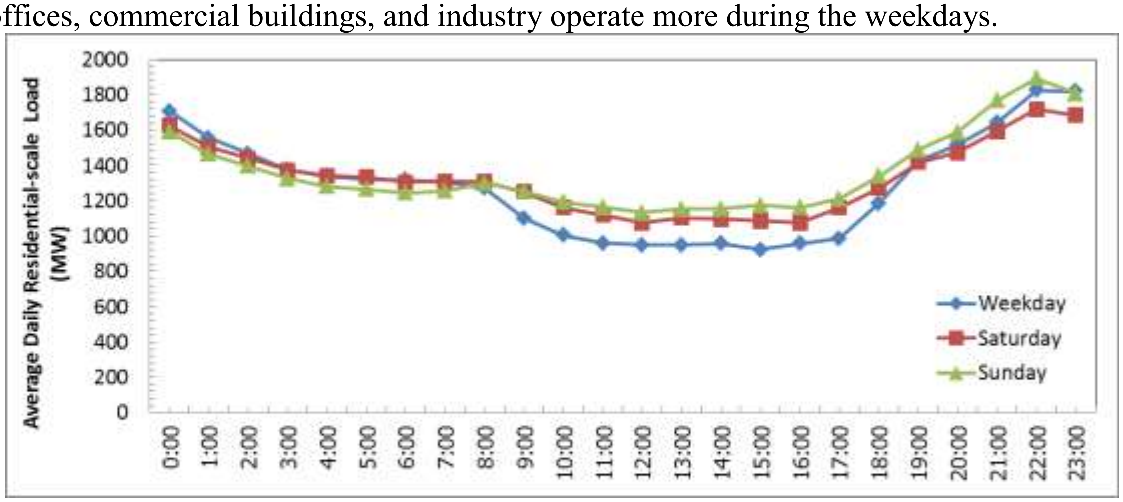

Figure 3.7: The Comparison between the Average of Weekday and Weekend Load of Residential Scale in Bangkok (Adapted from Metropolitan Electricity Authority, 2012).

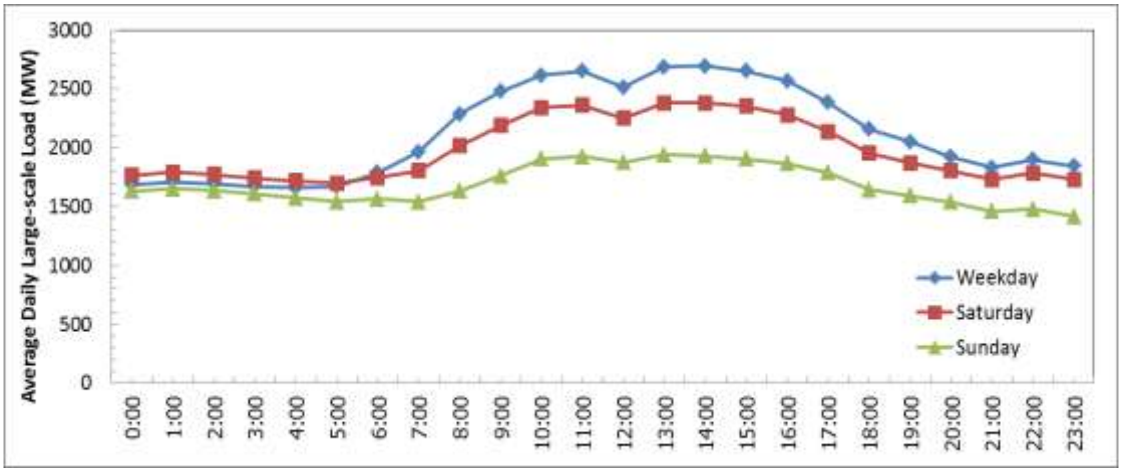

Figure 3.8: The Comparison between the Average of Weekday and Weekend Load of Large Scale in Bangkok (Adapted from Metropolitan Electricity Authority, 2012).

3.2 Methodology

After understanding both solar irradiance and load pattern in Bangkok, in this section, methodology of technical simulation is discussed. The objective of this work is to understand the relationship between distributed electricity from solar PV and load pattern of residential scale and large scale in order to better evaluate whether residential-scale solar PV is suitable for decreasing the current peak demand in Bangkok.

The PV Watts in the System Advisor Model (SAM) developed by the National Renewable Energy Laboratory is selected to use in this analysis. As seen in Fig 3.9, SAM uses two major inputs, the weather file and various system parameters that characterize the solar panels. The model calculates PV system output each hour of the year in units of alternating current electricity (AC), (kWh).

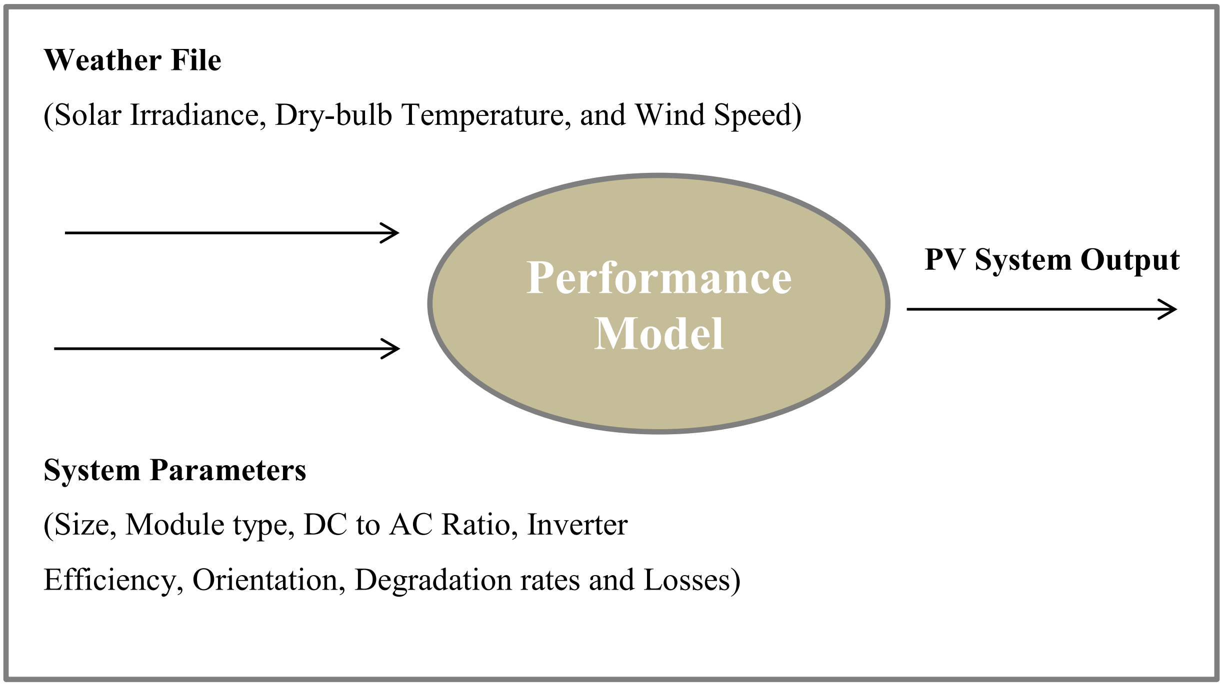

Figure 3.9: SAM Performance Model Diagram (Adapted from Gilman, 2015).

3.2.1 Data Input

The SAM weather file (solar resource) contains one year data at an hourly interval (8,760 data points). There are three required inputs in a weather file: solar irradiance, ambient dry-bulb temperature and wind speed at 10 meters from the ground (Dobos, 2014 and Gilman, 2015). The average values of these inputs based on SAM database are shown in Table 3.1.

The types of solar irradiance used in this simulation are direct normal or beam irradiance and diffuse horizontal irradiance. The direct normal irradiance (DNI) reaches a surface in a direct line (perpendicular) from the sun, while diffuse horizontal irradiance (DHI) touches a horizontal surface from all angles due to scatter and reflections. Normally, the total solar irradiance (global horizontal irradiance, GHI) on a surface can be calculated from two mentioned composition above as illustrated in Equation 3.1.

$$GHI = DNI \cos(Z) + DHI \tag{3.1}$$

Where;

GHI is the global horizontal irradiance.

DNI is the direct normal irradiance.

DHI is the diffuse horizontal irradiance.

Z is zenith angle measured from the vertical line from a surface to the location of the sun in the sky.

Performance Model Input	**Average data**
Direct Normal/Beam Irradiance	2.75 kWh/m^2/day
Diffuse Horizontal Irradiance	2.89 kWh/m^2/day
Temperature	28.5 °C
Wind Speed	2.9 m/s

Table 3.1: Performance Model Input Summary (Weather Data)

Apart from the weather file, system parameters related to this work is listed below (National Renewable Energy Laboratory, 2014):

- System Nameplate Size (kW)

According to the goal of a renewable energy plan (as of May 2015) explained in Chapter 2, 3,000 MW of solar PV rooftop capacity is assumed to be the total installation of this simulation based on Bangkok location.

- Module Type

The standard (crystalline) module covered by glass is used in this work. The efficiency of this module type is around 15 percent and the temperature coefficient is -0.47 percent/ °C (Dobos, 2014).

- Direct Current (DC) to Alternative Current (AC) Ratio

The DC to AC ratio or derate factor is the ratio of the inverter's AC rated size to the array's DC rated size. When the ratio increases, the system output (AC) from solar panels also increases. A typical value is generally between 1.10 to 1.25 depending on the location, array orientation and module cost.

- Inverter Efficiency

The Inverter efficiency is the DC to AC conversion efficiency. Similar to the derate ratio, the higher inverter efficiency leads to the higher AC output. The PVWatts calculates this efficiency based on the nominal efficiency and an efficiency curve in its database.

- Orientation

The array type that used in this thesis is fixed roof mount since it is suitable for rooftop installation especially for residential model due to the limited air flow between the module back and roof surface. Apart from the array type, tilt and azimuth degrees are two factors that need to input for solar panel orientation as shown in Fig. 3.10. Tilt is the degree from horizontal, where zero degree is horizontal, and 90 degrees is vertical, while azimuth (in degrees) is the array's orientation with respect to a line perpendicular to the equator. Thus, an azimuth value is 0°, 90°, 180°, and 270° when facing north, east, south, and west respectively. In Northern Hemisphere, like Bangkok, to maximize electricity generation the panel should be face south (180° and tilt from horizontal at the angle approzimately equal to the site's latitude (10-20°)

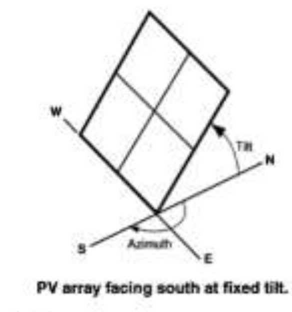

Figure 3.10: PV Array Facing South at Fixed Tilt.

(National Renewable Energy Laboratory, 2014)

- Degradation rate

The degradation rate is an annual reduction in system output due to temperature, UV exposure, and mechanical damage.

- Losses

In SAM, losses can be classified into ten types as below:

1. Soiling- Losses due to dirt, snow, and other foreign matter on the surface of PV that normally prevent solar radiation. It is higher at the high-traffic and polluted area.
2. Shading- This type of loss can also reduce the incident solar radiation from shadows caused by objects, such as trees, or by self-shading for fixed arrays or arrays with two-axis tracking. This loss can be calculated from Fig. 3.11. The figure shows the shading derate factor as function of ground cover ratio (GCR), which is the ratio of the PV array area to the total ground area. The typical value of GCR is generally between 0.4-0.6. In this simulation (fixed

arrays), the shading derate factor is a function of both GCR and tilt angles from horizontal.

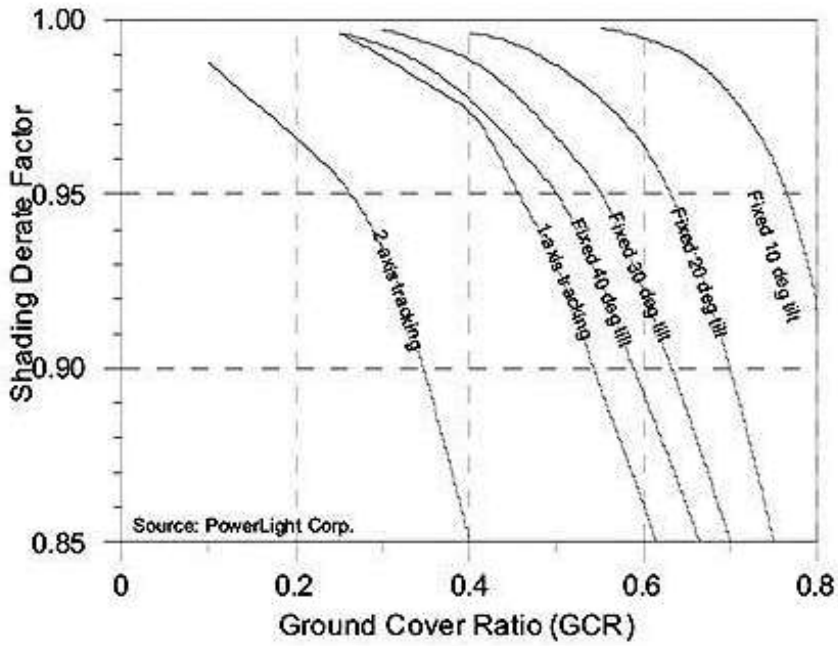

Figure 3.11: Shading Derate Factor versus GCR for Different Tracking Options (National Renewable Energy Laboratory, 2014)

After knowing the shading derate factor, shading loss can be defined as in Equation 3.2. For fixed array, in order to achieve less shading loss percentage, larger GCR and smaller tilt angle are required.

$$\% \text{ Shading loss} = (1\text{-Shading derate factor}) \times 100 \tag{3.2}$$

3. Snow- This loss is related to snow covering above the array. In Bangkok, there is never snow, so this value should be zero.

4. Mismatch- Electrical losses caused by manufacturing defectiveness between modules in the array that leads to different current-voltage characteristics.
5. Wiring- Resistive losses in the DC and AC connection in the system.
6. Connections- Resistive losses in electrical connectors.
7. Light-induced degradation- This is an effect of the reduction of array's power during the first few operating months.
8. Nameplate rating- Errors between nameplate rating and field measurement.
9. Age- Effect of weathering on performance of array overtime. It should be zero if the system already consider degradation rate.
10. Availability- Decreasing of system output due to scheduled or unscheduled system shutdown, maintenance, grid outages, etc.

In this simulation, the defaults of each loss from SAM are assumed. Then, the total losses for PV array can be calculated from the following Equation 3.3.

$$\text{Total losses} = \left(1 - \sum_{i} \frac{\text{Loss}_i}{100})\right) \times 100\ \% \qquad (3.3)$$

All system parameter inputs, as explained above, are described in Table 3.2 for using in SAM calculation method

System Parameters	Input
System Nameplate Size (MW)	3,000
Module Type	Standard
DC to AC Ratio	1.1
Inverter Efficiency (%)	96
Tilt Angle (degrees)	20
Azimuth Angle (degrees)	180
Degradation Rate (% per year)	0.5
Total Losses (%)	14.08
- Soiling (%)	2
- Shading (%)	3
- Snow (%)	0
- Mismatch (%)	2
- Wiring (%)	2
- Connections (%)	0.5
- Light-induced degradation (%)	1.5
- Nameplate rating	1
- Age	0
- Availability	3

Table 3.2: Performance Model Input Summary (System Parameters)

3.2.2 Model Simulation

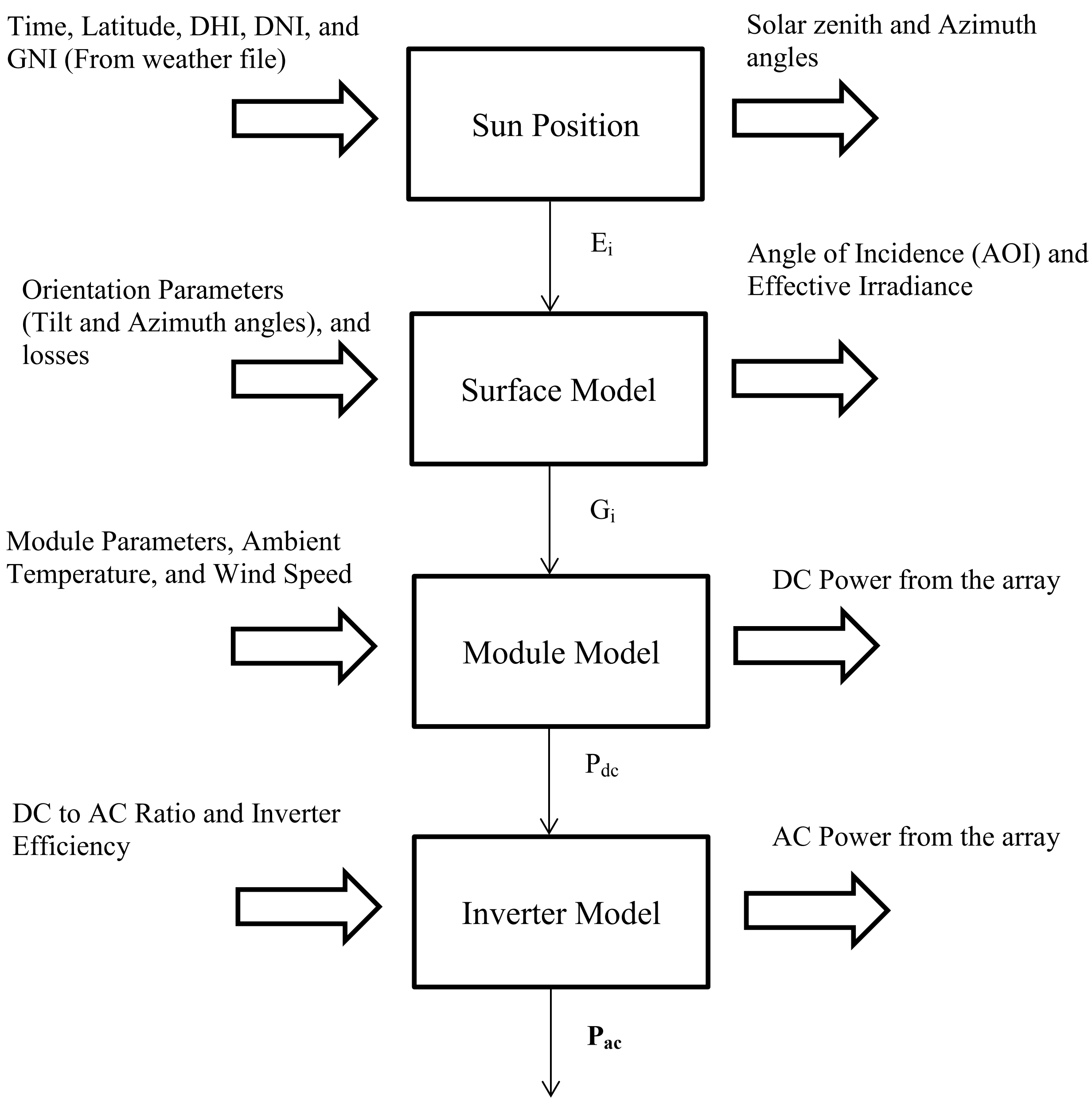

Figure 3.12: The PVWatts Performance Model Block Diagram.

(Adapted from Gilman, 2015)

SAM performance model for PVWatts is summarized in Fig. 3.12. There are four main models that the simulation uses in order to calculate AC power output from solar PV: sun position, surface model, module model and inverter model, (Gilman, 2015 and Dobos, 2014).

1. Sun Position

According to Michalsky (1998), PVWatts calculates the hourly sun position using the Astronomical Almanac's Algorithm in order to determine the solar zenith (Z_{sun}) and azimuth angles (γ_{sun}). The zenith angle is measured from vertical, while the azimuth angle is measured clockwise from North as shown in Fig. 3.13. The sun position is usually calculated at the midpoint of the hour. These two angles are used as parameters in the next module called surface module.

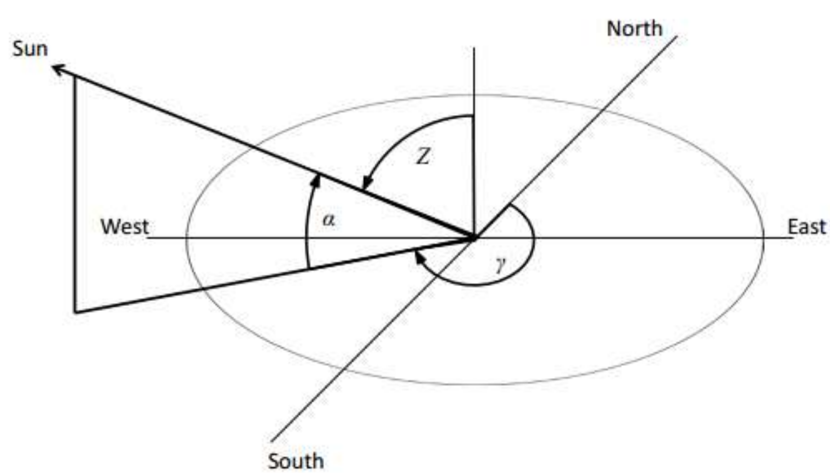

Figure 3.13: Sun Angles

(National Renewable Energy Laboratory, 2014

2. Surface Model

The PVWatts considers the array orientation using tilt angle (β) and azimuth angle (Ψ) as shown in Fig. 3.14. Considering the solar incidence angle or angle of incidence (AOI) (Θ), it is the angle between beam normal irradiance and a line normal to the subarray surface (Fig. 3.14) as a function of the solar zenith angle (Z_{sun}), azimuth angle (γ_{sun}), surface tilt angle (β) and surface azimuth angle (Ψ) as listed in Equation 3.4.

For fixed tilt panels;

$$\Theta = \cos^{-1} [\sin (Z_{sun}) \cos (\Psi - \gamma_{sun}) \sin (\beta) + \cos (Z_{sun}) \cos (\beta)] \quad (3.4)$$

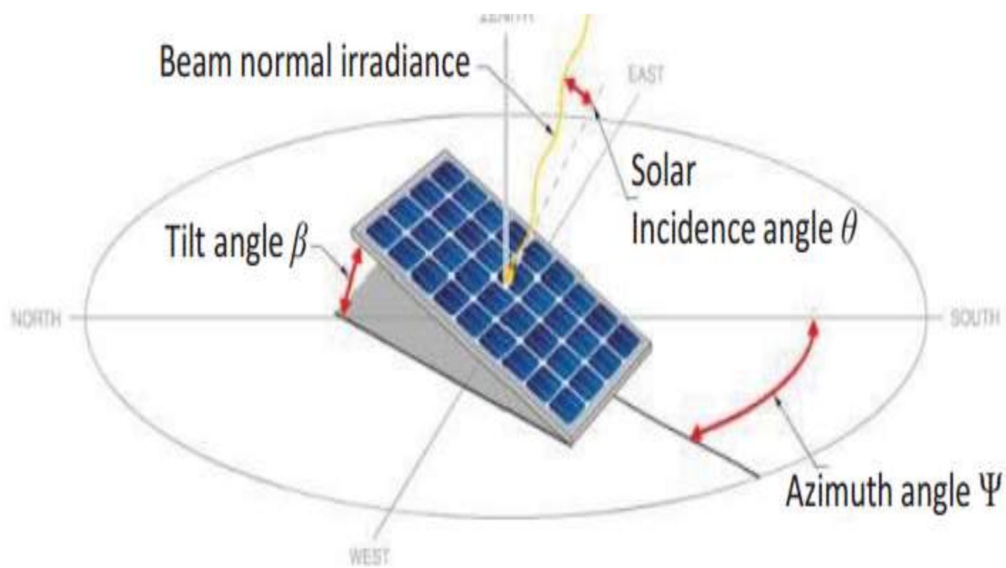

Figure 3.14: Array Orientation and Surface Angles

(Gilman, 2015)

After defining the angle of incidence, Plane-of-Array irradiance (I_{poa}) before soiling and shading can be calculated using the Perez 1990 algorithm (Dobos, 2014) as explained in Equation 3.5.

$$I_{poa} = I_b + I_{d,sky} + I_{d,ground} \tag{3.5}$$

Where;

I_{poa} is the plane-of-array irradiance (Irradiance Incident on the PV array before soiling and shading,

I_b is the plane-of-array beam component. It is the direct normal irradiance (DNI) from weather file multiplied by the cosine of angle of incidence (Θ),

$I_{d,sky}$ is the total sky diffuse irradiance. Using the isotropic model (Gilman, 2015), $I_{d,sky}$ can be calculated using the diffuse horizontal irradiance (DHI) and surface tilt angle from Equation 3.6.

$$I_{d,sky} = \mathrm{DHI} \times \left(\frac{1+\cos\beta}{2}\right) \tag{3.6}$$

$I_{d,ground}$ is the incident ground-reflected irradiance, which is diffuse solar irradiance that reaches the array surface after reflecting from the ground illustrated in Equation 3.7.

$$I_{d,ground} = alb\,(\mathrm{DNI}\cos Z_{sun} + I_{d,sky}) \times \left(\frac{1+\cos\beta}{2}\right) \tag{3.7}$$

Note that *Alb* stands for the albedo or ground reflectance indicated in the weather file assuming that the albedo is constant over a month (0.18 for Bangkok, Thailand).

When getting an estimated of Plane-of-Array irradiance (I_{poa}), then, the effective irradiance (G_{poa}) needs to be considered. The effective irradiance is the incident that including shading, soiling and other losses of the array as shown in Equation 3.8 (Dobos, 2014).

$$G_{poa} = G_b + G_{d,sky} + G_{d,ground} \tag{3.8}$$

Where;

G_{poa} is the irradiance incident on the PV array after soiling and shading,

G_b is the effective beam irradiance. It is the plane-of-array beam component (I_b) multiplied by the shading and soiling factor from beam component (S_b) from the PVWatts's database,

$G_{d,sky}$ is the effective diffuse irradiance. It is the total sky diffuse irradiance ($I_{d,sky}$) from Equation 3.6 multiplied by the shading and soiling factor for diffuse component (S_d) from the PVWatts's database,

$G_{d,ground}$ is the effective ground-reflected irradiance. It is the incident ground-reflected irradiance ($I_{d,ground}$) from Equation 3.7 multiplied by the shading and soiling factor for ground-reflected component (S_{rss}) from the PVWatts's database.

Next, the PV Watts applies a correction to adjust the G_{poa} to take an account for reflection losses. For the standard module, a single slab model (considering the transmittance through glass with the index of refraction of 1.526 (Desoto *et al.*, 2006) is used in the calculation as shown in Fig. 3.15.

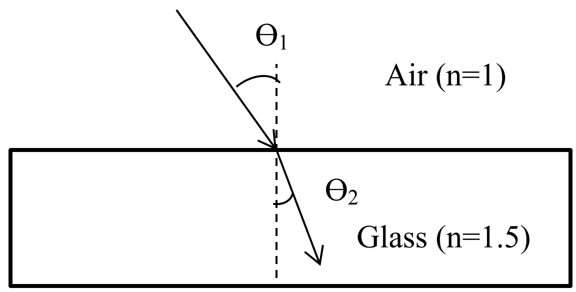

Figure 3.15: Diagram of Single Slab Model.

The angle of refraction into the glass cover (Θ_2) into the glass can be calculated with Snell's law as in Equation 3.9

$$\theta_2 = \arcsin(\frac{n_{air}}{n_{glass}} \times \sin\theta_1) \tag{3.9}$$

Then, the transmittance of solar incident through the glass is calculated using Fresnel's Equation as shown in Equation 3.10 below.

$$\tau_{glass} = 1 - \left(0.5 \times \frac{\sin(\theta_2-\theta_1)^2}{\sin(\theta_2+\theta_1)^2}\right) + \left(\frac{\tan(\theta_2-\theta_1)^2}{\tan(\theta_2+\theta_1)^2}\right) \tag{3.10}$$

Afterward, the transmitted plane-of-array irradiance after shading and soiling (G_{tr}) is defined as a multiply between the transmittance of glass and the irradiance incident on the PV array after soiling and shading (G_{poa}) as indicated in Equation 3.11 (Dobos, 2014).

This transmitted irradiance will be used to calculate in the module model in the next section.

$$G_{tr} = (\tau_{glass})(G_{poa}) \tag{3.11}$$

3. Module Model

The PVWatts determines the DC power output from an array using a specified nameplate, transmitted plane-of-array irradiance, cell temperature and temperature coefficient shown in Equation 3.12 (Dobos, 2014).

$$P_{dc} = \frac{G_{tr}}{1{,}000} \times P_{dc0} \times (1 + \gamma(T_{cell} - T_{ref})) \tag{3.12}$$

Where;

P_{dc} is the DC power output from an array (W),

G_{tr} is the transmitted plane-of-array irradiance after shading and soiling (W/m^2),

P_{dc0} is the system nameplate power outing as a system input as described in Table 3.2 (W),

γ is the temperature coefficient (-0.47 percent/ °C) for standard module as illustrated in the input section,

T_{cell} is the cell temperature. The PVWatts assumes the cell temperature, at a height of 5 m above the ground and the wind speed mentioned in the weather file, is roughly at 45 °C,

T_{ref} is the reference temperature (25 °C).

4. Inverter Model

After getting DC power output from the module model, the inverter model is used to calculate DC to AC power output based on inverter efficiency in Table 3.2. The inverter model in PVWatts is built from an analysis of California Energy Commission (CEC) inverter performance data (Dobos, 2014) described in Equation 3.13.

$$\eta = \frac{\eta_{nom}}{\eta_{ref}} - (0.0162 \times \delta) - \left(\frac{0.0059}{\delta}\right) + 0.9858 \tag{3.13}$$

Where;

η is the inverter efficiency,

η_{nom} is the inverter efficiency. The default value is 0.96,

η_{ref} is the reference inverter efficiency from CEC. The default value is 0.9637,

δ is the ratio between P_{dc} to P_{dc0}.

The AC power output (P_{ac}), which is final desired output, can be defined from the inverter efficiency and DC power output shown in Equation 3.14. When the predicted AC power output is more than the nameplate rating (P_{dc0}) , the AC output is going to be equal to the nameplate value (P_{ac0}). For years 2 and later, degradation rate is needed to consider since power generated from solar PV decreases every year based on the degradation rate.

$$P_{ac} = \begin{cases} \boldsymbol{\eta}\, P_{dc} & : 0 < P_{dc} < P_{dc0} \\ P_{ac0} = \boldsymbol{\eta}_{nom}\, P_{dc0} & : P_{dc} > P_{dc0} \\ 0 & : P_{dc} = 0 \end{cases} \tag{3.14}$$

3.3 Results

On objective of this thesis is to make a comparison between hourly (AC) power output from solar photovoltaic panels (from the PVWatts) installed in Bangkok and electricity load (Fig 3.6). This analysis informs us of the opportunity for solar PV installations to reduce electricity demands from the electric grid in Bangkok area for both residential scale and large scale.

3.3.1 Overview (Total Bangkok Load)

The pattern of power output from 3,000 MW installed solar PV (assuming south-facing panels) and total loads in greater Bangkok in a typical daily (an average day, 2012) basis are quite matched as in Fig. 3.16. The peak of power output from both PV panels and total load is from 9am to 3pm approximately. The 3,000 MW solar PV installation is able to decrease peak demand from 7,696 MW to 6,657 MW (or by 13.5 percent) in Bangkok. In addition, focusing on daily basis, the total electricity demand from the grid can be decreased from 147,374 MWh to 135,202 MWh (or by 8 percent) after 3,000 MW solar PV installation.

In the Section 3.3.2 and 3.3.3 will discuss the relationship of distributed 3,000 MW PV and both residential and large-scale load in order to make a comparison and understand the possibility of residential solar PV implementation in Bangkok.

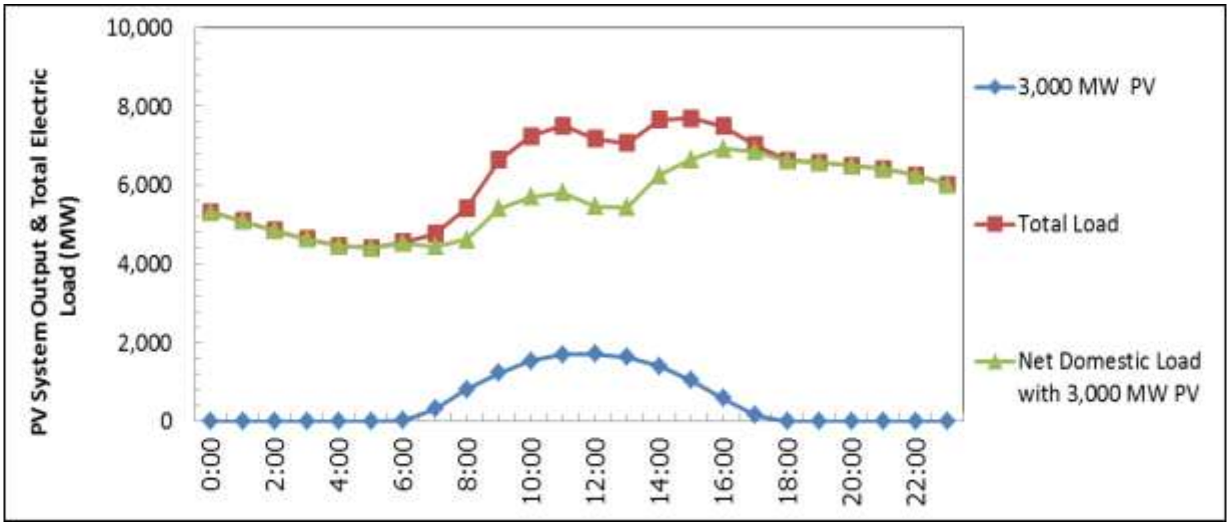

Figure 3.16: The relationship between total Bangkok Load and Distributed Generation patterns of the average day.

3.3.2 Residential scale

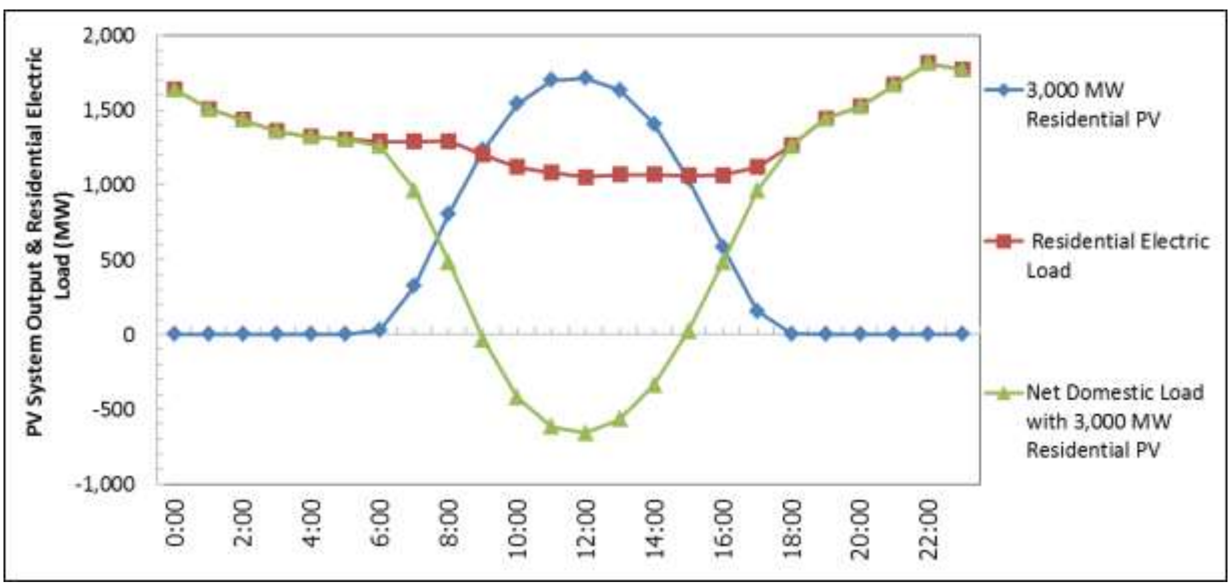

Figure 3.17: Residential Load and Distributed Generation patterns of the average day are not aligned.

Fig. 3.17 illustrates a typical daily (an average day, 2012) pattern of power output from 3,000 MW installed solar PV (assuming south-facing panels) and residential electric loads in greater Bangkok. The peak of power output from PV panels is from 9am to 3pm, while the electric load peak is at night (9 pm until midnight). However, even if the solar PV output does not decrease peak load of electricity use in Bangkok, PV is still useful in terms of lowering power demand from the grid each day, especially at noon. Considering daily generation, the total electricity demand of the grid in one day can be reduced from 31,754 MWh to 19,581 MWh or by 38 percent by installing 3,000 MW of solar PV.

Additionally, electricity from solar panels, generated around noon, is able to exceed residential electricity demands. In the midday, the residential distributed electricity from 3,000 MW of solar PV is 130 percent of residential load. If generated electricity from PV during midday can be stored in battery or sell back to the grid, it could benefit energy security in Thailand since Thailand might be able to reduce imports of fossil fuels for electricity generation.

When compared to the U.S., Thai residential electric load patterns are quite different. This difference is due to the fact that many residential-scale electric loads in the U.S. peak in the afternoon (particularly due to air conditioning load in the summer) that somewhat better correspond with solar insolation, while in Thailand the peak in residential electric load is after sundown. If Thailand resident incomes increase, we might expect more air conditioning in the future and a new peak demand for residential electricity during the afternoon.

3.3.3 Large scale

A typical daily (an average day, 2012) pattern of power output from 3,000 MW installed solar PV (assuming south-facing panels) and large electric loads in greater Bangkok are well-matched (see Fig. 3.18). The peak of power output from both PV panels and large-scale load is from 9am to 3pm. With large-scale, PV generation can still lower grid electricity demand in each day, especially at noon. Focusing on all day basis, sum of electricity demand from the grid can be decreased from 46,357 MWh to 34,185 MWh or by 26 percent by power generation from 3,000 MW of solar PV.

There are important differences between residential scale and large scale load. The 3,000 MW of solar PV panels decrease large scale peak load and shift it in time from 2,337 MW at 1 pm to 1,946 MW at 5 pm for a decrease of 16.7 percent of large scale load in Bangkok. Moreover, electricity from solar panels, generated around noon, is not able to exceed electric demands in daily basis. Thus, in the midday, the large-scale distributed electricity from solar PV is 77 percent of large-scale load as illustrated in Fig. 3.18.

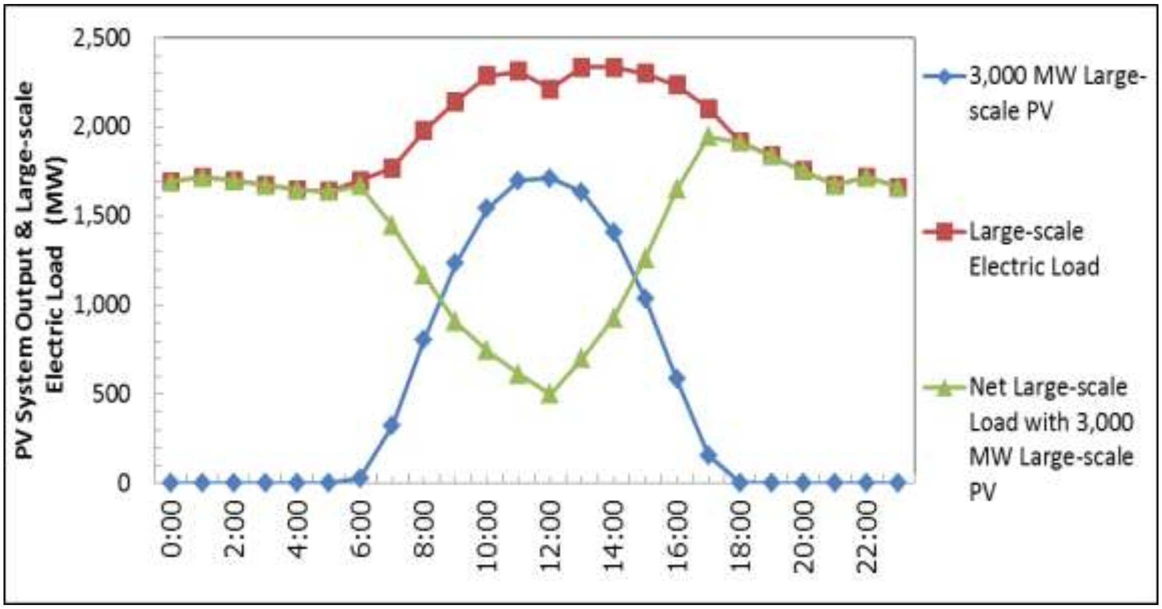

Figure 3.18: Large-scale Load and Distributed Generation patterns of the average day are well aligned.

An installed PV capacity of 3,800 MW can cause the net load of large-scale load to be zero MW on a typical day at noon as shown in Fig. 3.19. One potential benefit of distributed PV is to decrease decreasing peak electricity demand from the grid (and the associated transmission and distribution investments), which is one of the problems in Thailand's energy situation as mentioned in Chapter 2 (Section 2.2.2).

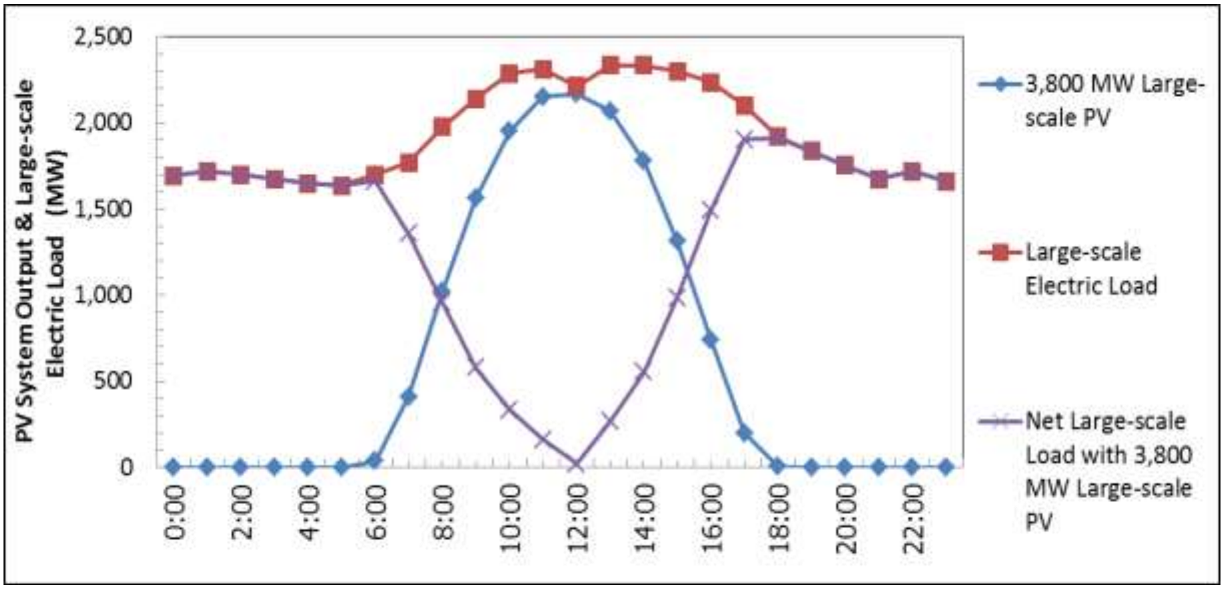

Figure 3.19: Distributed generation can reduce a midday load to be zero when installing 3,800 MW of solar PV.

3.4 Technical barriers

After understanding electric load and distributed generation pattern of both residential scale and large scale, it is predictable that solar PV can decrease the need for fossil fuel consumption (for electric power) in Thailand. However, several technical barriers still impede progress of solar installation. Based on Chaianong and Pharino (2015), technical barriers, normally, come from lack of technical experiences and solar efficiency problems as described below.

3.4.1 Lack of Technical Experiences

Technical experiences include both PV panels' production technology and skillful manpower. The ability to install and maintain solar PV system is essential for Thailand to further increase the successful installation experiences. Currently, Thailand has used imported solar PV technology from many countries, including Japan and China.

However, the imported technology limits growth and development of local solar industries. China is one of the great examples of countries that used their own technology to develop solar PV implementation. Certainly, China’s technology should work great in their climate and condition and also its price is lower than imported from other countries.

In addition, Thai government might need to allocate expenses to both hands-on education and research and development (R&D) programs on improvement of solar technology to better understand the conditions of PV installation. Germany is another country that has a very high rate of solar installation. In 2000, the country spent approximately 3 percent of all national GDP on energy R&D. In addition, at the EU level, 53.3 billion EUR was spent on solar technology improvement research during 2007-2013. (Chaianong and Pharino, 2015 and Runci 2004).

Apart from solar PV technology, skillful manpower is another issue that is needed to development solar PV in Thailand. As indicated above, both hands-on education and R&D programs not only improve solar PV technology but also develop a skilled workforce in Thailand. If the solar workers can install and maintain the system more effectively, the efficiency of solar PV should be increased. Consequently, Thai residents, including Bangkok residents, might gain interest and confidence to start installing solar PV in their households.

3.4.2 Solar PV Efficiency Problems

In Thailand, many users are interested to install solar PV; however, they are not sure about the power generation quality and other technical problems regarding PV installation and selling electricity back to the grid. These issues might cause hesitation to install solar PV.

Power stability is one of the most essential factors. Normally, it is essential that any inverter should supply the stable harmonic of electricity to the grid otherwise it might fail to operate or cause voltage deviation for the entire system, potentially causing a blackout. The solutions for voltage stability issues are to use a battery and transformer that can store electricity or smart inverters to help maintain voltage stability in case the users want to sell electricity back to the grid (Eltawil and Zhengming, 2010).

Additionally, power losses are another issue that related to solar PV efficiency. Unstable weather and pollution in atmosphere might increase power losses in PV panels by creating some hot spots or heating side effect that might degrade solar panels more quickly. PV owners need to maintain solar panels by removing dust accumulation from pollution. Also, to optimize the performance of solar panels, the users should install solar PV properly by considering both tilt and azimuth angle to receive the highest performance of sun radiation.

The mentioned barriers above are important to understand for promoting solar PV rooftop in Bangkok for both residential scale and large scale, since in order to enhance solar installation rate in Thailand, not only understanding load and distributed energy pattern, but also investigating the technical barriers is required.

3.5 Technical Analysis Summary

Solar radiation in Bangkok is approximately 5 kWh/m^2/day. It is high in the summer (February-April). In winter and rainy season, the sun radiation is affected by the Northeast and the Southwest monsoon respectively causing lower solar irradiance across the country. Looking deeply into hourly solar irradiance in Bangkok, the peak of sun intensity is from 9am-3pm. This period of day can be a perfect time for generating electricity from solar PV in Bangkok.

According to load pattern in Bangkok, for the household, the peak of electricity in each day is at night (around 9 pm till midnight) due to the fact that most residents in Bangkok usually work all day and return home in the evening onwards. Even during weekend, the residential pattern of load is still the same except that at noon, load in weekend is more than weekday, and this is because Bangkok residents stay at home during much of the weekend. Per large scale users, most of them usually consume electricity much more during daytime since all activities are running at that time period. The large scale load pattern is quite similar to the U.S. Generally, weekday load of large scale is more than weekend due to the fact that most office work, such as accounting, secretary, and planning, occurs during weekdays while equipment in the industry operates during all days.

Solar irradiance and load of an average day in 2012 are main inputs for the PVWatts. Solar nameplate is assumed to be 3,000 MW (assuming south-facing panels). All system parameters are described in Table 3.2. Next, the differences between load and distributed energy pattern of residential scale and large scale are summarized in Table 3.3.

	Residential Scale	Large Scale
Peak Load	9 pm until midnight	9am-3pm
Load and Distributed Energy Pattern	Not same pattern	Same pattern
Sum of Electricity Demand from the grid (one day basis) after 3,000 MW PV installation	Decrease 38%	Decrease 26%
% Distributed PV Energy compared to Midday Load	130%	77%

Table 3.3: Load and Distributed Energy Pattern of Residential and Large-scale Load.

From Table 3.3, load and distributed energy of large scale seems to be better matched when compared to residential scale. After 3,000 MW solar PV installation, the sum of electricity load consumption from the grid (one day basis) decreases 38 percent and 26 percent for residential and large scale, respectively. However, during midday, energy generated from the solar PV is able to exceed load demand of residential scale (PV generation is 130 percent of midday load), so it would be great to store or sell energy back to the grid in order to reduce electricity generation from fossil fuels.

Technical barriers are another issue that needs to be considered in order to increase solar implementation rate in Bangkok. Lacking technical experiences (both technology and manpower) is main issue for technical barriers. In addition, orientation of the panels, temperature and other weather conditions are factors that can affect the efficiency of solar rooftop in Bangkok. Thus, it is necessary to understand these factors before installing solar panels more effectively; however, it is also required skillful manpower to set it up.

Chapter 4: Economic Analysis

This chapter presents the economic analysis of solar PV implementation in Bangkok. The first part (Section 4.1) of this chapter introduces the overview of power generation cost in Thailand compared to the U.S., and the general income and expense of residential scale and large scale in order to understand the economics for the consumers. The second part (Section 4.2) reviews the methodology of Levelized Cost of Energy (LCOE) calculation that has been used in this analysis. In Section 4.3, all LCOE results are reported and compared to electricity price in both Thailand and the U.S. After that, the changes of expense and saving due to LCOE of Solar PV is calculated to understand whether the consumers in Bangkok are able to afford it or not. Finally, Section 4.4 summarizes the economic analysis.

4.1 Introduction

4.1.1 Power Generator Cost

Considering installed cost, both Thailand and the U.S., low-carbon energy power plants such as biomass, solar and nuclear, have higher installed costs than fossil fuel-based power plants as shown in Fig. 4.1. Nuclear seems to have the highest installed cost followed by biomass, hydro, solar, coal and natural gas. Focusing on solar PV in Thailand, as for residential scale, the installed cost is 1.88 US$ per W, while large-scale's installed cost is 1.72 US$ per W. Similarly to the U.S., large-scale solar PV seems to have cheaper installed cost than residential scale. In Fig. 4.1, it is noticeable that the installed cost of both scales in the U.S. is higher than in Thailand. The reasons might be from labor cost and solar panels cost. Solar panels that used in Thailand, normally, come from China and Japan. Certainly, solar panels produced in China are a lot cheaper due to the large-scale of manufacturing. For example, China's 260 W solar cell price is 0.6 US$ per watt, while in the U.S., for the same capacity (260W), price is 0.9 US$ per watt, a price still reflective of imported panels (Made in china, 2015 and Wholesale solar, 2015). Also, wages in Thailand are lower than the U.S. According to National Conference of State Legislatures (2015), the federal minimum wage is 7.25 US$ per hour, while based on Thailand Board of Investment, minimum wage per day is 8.87 US$[1]. These might be some economic advantages for installing solar PV in Thailand.

Based on operating costs in Fig. 4.1, renewable energy plants tend to be very low on operating costs except from biomass, which is only one type of renewable energy that has an operating cost more than fossil-based in both Thailand and the U.S.

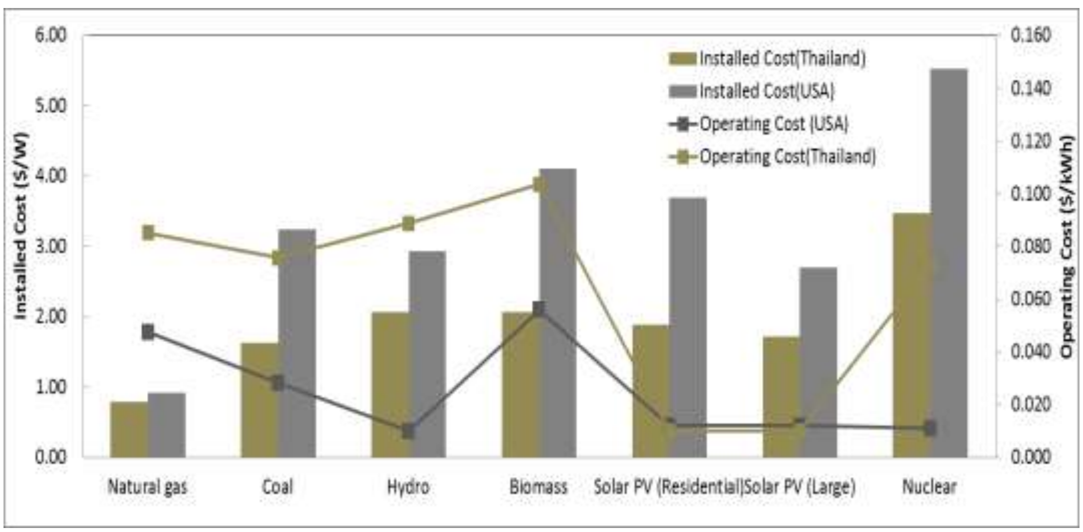

Figure 4.1: Different Power Generator Cost (Installed Cost and Operating Cost) of Thailand[2] and the U.S (Adapted from Kasetsart University, 2012; Kurovat, 2012; Lazard, 2014; Rhodes, 2015 and Tongsopit, 2014).

[1]The minimum daily wage is 295 Baht/day.

[2] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

In the U.S., hydro, solar and nuclear energy resources have slightly the same operating costs, approximately 0.01 US$ per kWh, whereas fossil fuel-based has an operating costs of 0.02-0.04 US$ per kWh. Per Thailand, each type of energy resource seems to have a higher operating cost than the U.S. due to a higher fuel cost. Natural gas and coal in Thailand has an operating cost of 0.08-0.09 US$ per kWh, while both nuclear and hydro have a higher operating cost (0.07-0.09 US$ per kWh) than solar, which costs around 0.01 US$ per kWh for both residential and large scale. Unlike conventional power plants using coal and natural gas, solar PV has no fuel costs and relatively low operating and maintenance (O&M) costs, which should be one of the advantages for installing solar PV.

4.1.2 General Income and Expense

4.1.2.1 Residential scale in Bangkok

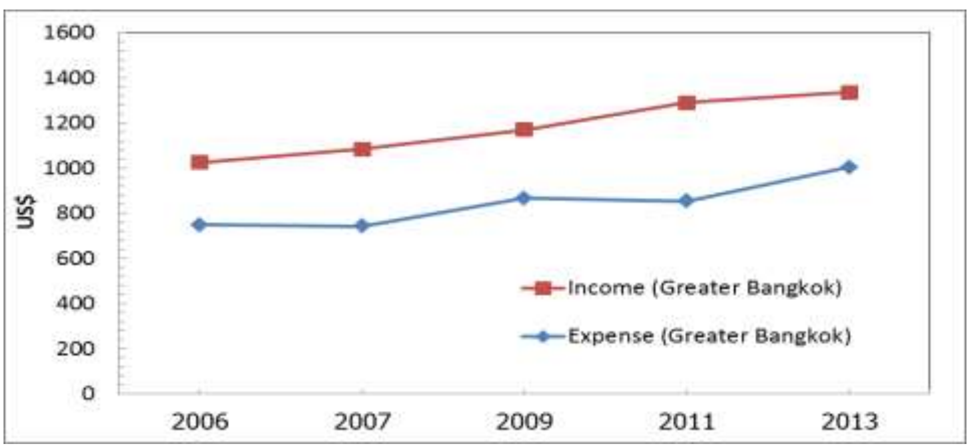

Figure 4.2: Monthly Income and Expense per Household in Bangkok from 2006-2013[3]

(Adapted from National Statistical Office, 2014)

[3] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

In greater Bangkok, populations have higher income and expenses (on all items) compared to the whole country (National Statistical Office, 2014). As shown in Fig. 4.2, monthly income per person is approximately 1,000-1,400 US$, while expenses, including taxes, are around 72-75 percent of their income. Thus, most people in Bangkok tend to save a considerable portion of their income every year. The installation costs of residential- PV in Bangkok are near 2.0 US$/W, and average loads per household per month are around 400 kWh (Metropolitan Electricity Authority, 2012). Thus, installing PV that generates 400 kWh/month in Bangkok area should cost around 8,000 US$. This is much higher than monthly household incomes. However, since, they seem to save their income every month, it might be possible to use their saving to invest on solar PV.

Approximately 4 percent of household expenses are for electricity payment. It is possible that people in Bangkok might not be interested in decreasing electricity costs compared to other expenses that account for more than 90 percent of their total expenses (Fig. 4.3).

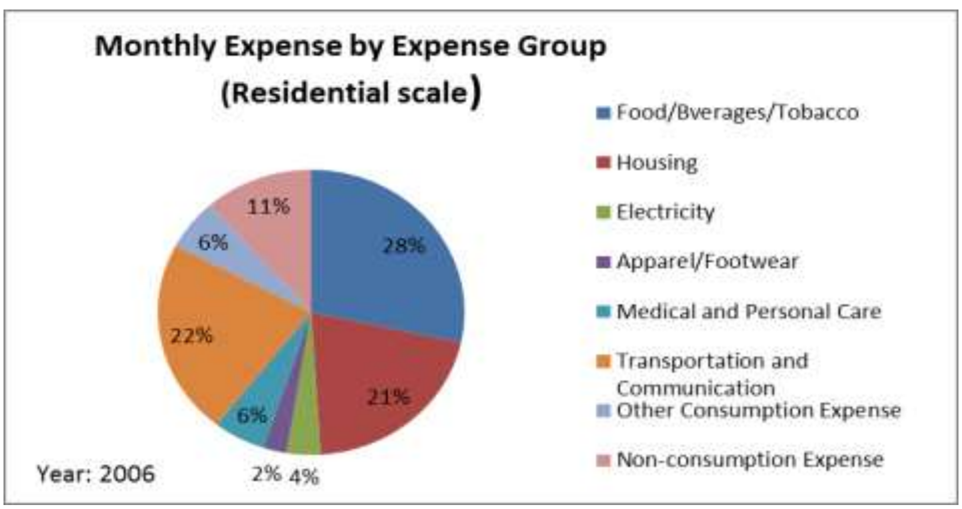

Figure 4.3: Monthly Expense by Expense Group in Greater Bangkok (Adapted from National Statistical Office, 2014).

4.1.2.2 Large scale in Bangkok

In this study, manufacturing and hotels are two examples of large scale users. Based on Fig. 4.4, monthly income per large scale user is approximately 40,000-60,000 US$, while expenses, including taxes,are around 78 and 50 percent of their income for manufacturing and hotel, respectively. Thus, they tend to save a significant portion of their income every year as profit, and they can use some of this profit to install solar PV.

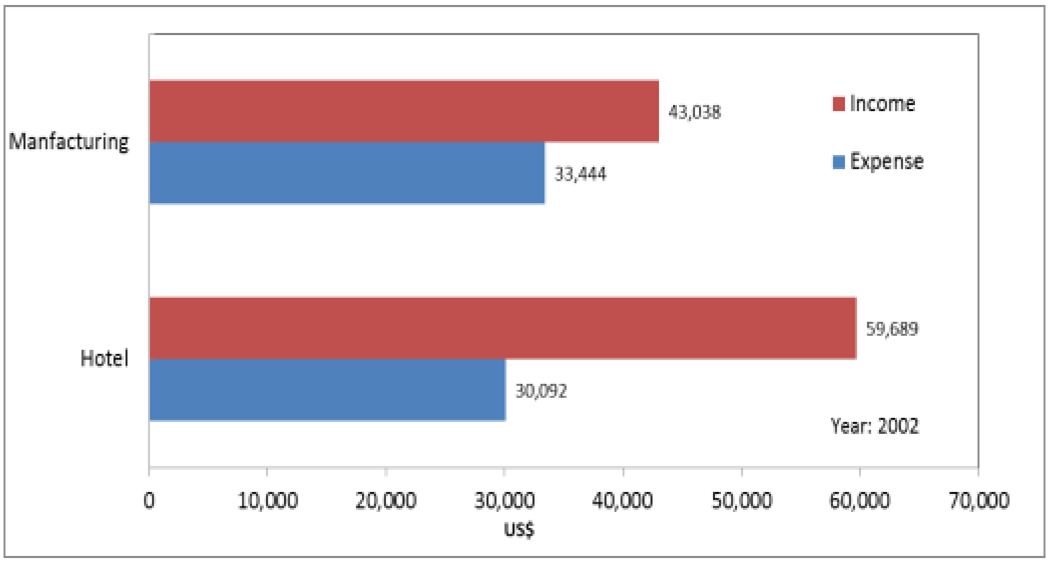

Figure 4.4: Monthly Income and Expense of Manufacturing and Hotel[4]

(Adapted from National Statistical Office, 2003)

For the manufacturing, electricity payments account for 2 percent of their expenses each month, while for hotels, 13 percent of their expenses are for electricity payments, much higher than manufacturing and also residential scale users. Even if hotel users spend their expenses on electricity more than manufacturing users, it might be

[4] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

possible that large-scale users in Bangkok might not be interested in decreasing electricity costs compared to other expenses that account for more than 90 percent of their total expenses (Fig. 4.5-4.6).

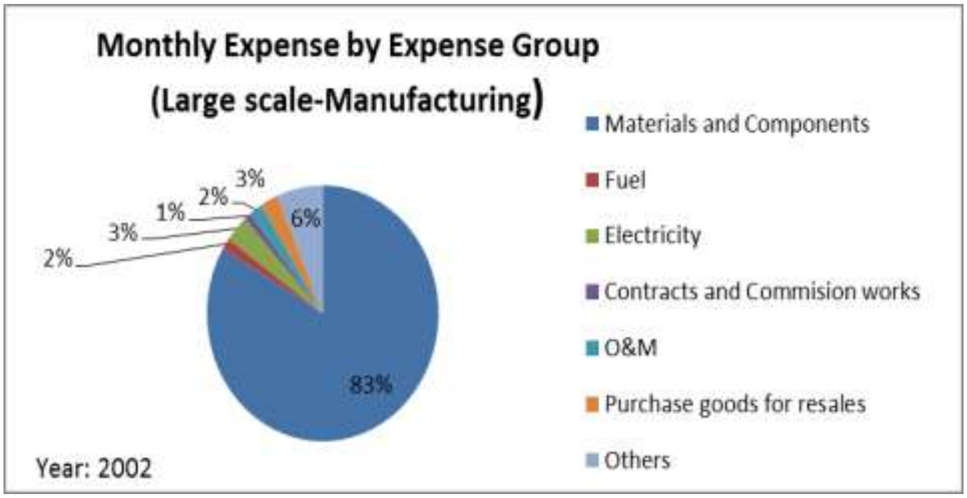

Figure 4.5: Monthly Expense by Expense Group of Manufacturing in Thailand

(Adapted from National Statistical Office, 2003)

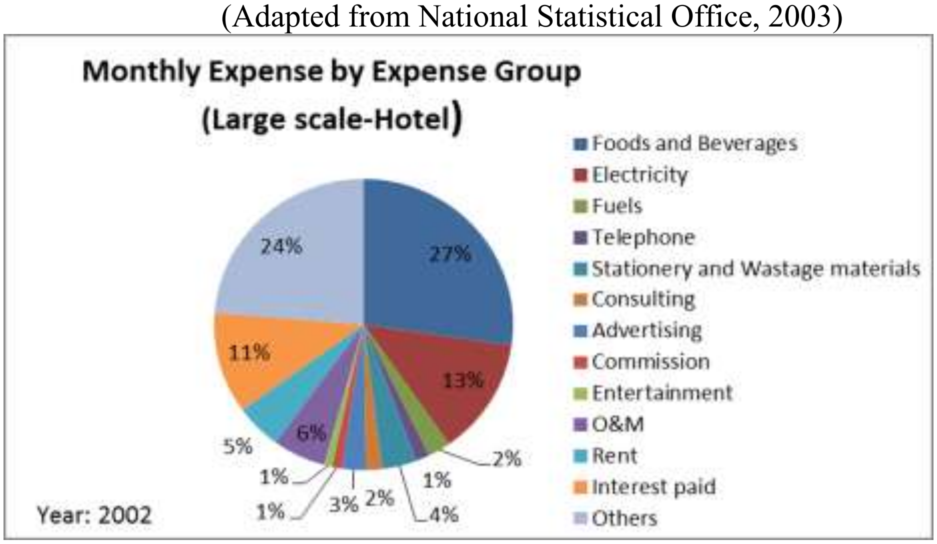

Figure 4.6: Monthly Expense by Expense Group of Hotel in Thailand

(Adapted from National Statistical Office, 2003)

4.2 Methodology

In this economic analysis, the levelized cost of energy (LCOE) is used for comparing electricity generation costs among several technologies. Normally, it is calculated by accounting for all expected lifetime costs, such as installed costs, operating and maintenance costs, taxes, and insurance, divided be generated energy in kWh. All costs are adjusted based on the inflation and discount rate that account for the time-value of money.

The PVWatts in SAM is selected to use for a LCOE calculation. The LCOE of solar PV for both residential scale and large scale in Bangkok is calculated to compare to the U.S.' LCOE of solar from Lazard (2014). According to National Renewable Energy Laboratory (2014), LCOE's formula is described in Equation 4.1 and also each parameter that requires inputting to the PVWatts for using in Equation 4.1 is summarized in Table 4.

$$\mathrm{LCOE} = \frac{C_0 + \sum_1^N \frac{C_n}{(1-d_{nom})^n}}{\sum_1^N \frac{Q_n}{(1-d_{nom})^n}} \tag{4.1}$$

Where;

C_0 = Project's initial cost (Installed cost),

C_n = Annual project's cost in year n (Operating cost and Insurance cost),

Q_n = Electricity generated by the system in year n (From the PVWatts in technical analysis section),

d_{nom} = The nominal discount rate with inflation (calculating from real discount rate and nominal inflation rate),

N = Analysis period.

System Parameters	Residential Scale	Large Scale	References
Installed Cost [5] ($/W)	1.88	1.72	Kasetsart University, 2012 and Kurovat, 2014
Operating Cost ($/kWh)[6]	0.01	0.01	Tongsopit, 2014
Operating Cost Escalation Rate (%)	3	3	Dobos, 2014 and Gilman, 2015
Insurance Cost (% of installed cost)	0.5	0.5	Tongsopit, 2014
Real Discount Rate (%)	3	3	Index Mundi, 2014
Nominal Inflation Rate (%)	2.8	2.8	World Bank, 2014
Nominal Discount Rate (%)	5.9	5.9	Index Mundi, 2014 and World Bank, 2014
Analysis Period (Years)	25	25	Tongsopit, 2014

Table 4.1: LCOE Calculation Input Summary (System Parameters).[7]

4.3 Results

As stated above, LCOE of solar PV in Bangkok is calculated from the PVWatts for both residential scale and large scale in order to compare with current electricity price in Thailand. To be economically viable, the project's LCOE must be equal to or less than the average retail electricity rate. As for the U.S., LCOE of solar is from Lazard (2014). They used 10 percent discount rate and 0.8 percent inflation in the calculation. Since the

[5] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

[6] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

[7] Under policy assumption

discount rate and inflation rate used in the calculation are not the same between Thailand and the U.S., the comparison between Thailand and the U.S. cannot be done. However, it is beneficial in terms of better understanding the trend of solar PV's LCOE from another country and also how close between solar and electricity price is. Consequently, the policies or incentives are able to evaluate based on the current price of solar PV in Bangkok and how much Bangkok residents pay for electricity from the grid right now.

4.3.1 LCOE of solar PV versus Electricity Price

Country	Residential PV (US$/kWh)	Large-scale PV (US$/kWh)	Grid (US$/kWh)
Thailand	0.14	0.13	0.12
The U.S.	0.18-0.27	0.13-0.18	0.10
	0.14-0.20*	0.096-0.14*	

*Subsidized price

Table 4.2: LCOE versus Electricity Price of Thailand and the U.S. (Adapted from Energy Information Administration (2015); Lazard (2014); Metropolitan Electricity Authority (2013c)).

Per Table 4.2, residential solar PV of both Thailand and the U.S. is higher than large scale. Focusing on Thailand, LCOE of residential solar PV calculated from the PVWatts is 0.14 US$ per kWh, while large –scale solar PV has a LCOE of 0.13 US$ per kWh. Compared LCOE to the grid electricity price, energy cost of solar is still more expensive than grid electricity. In Thailand, grid electricity price average is 0.12 US$ per kWh. In the U.S., LCOE of solar PV is 0.18-0.27 $/kWh and 0.13-0.18 $/kWh for residential scale and large scale, respectively, which are higher than grid electricity of

0.10 US$ per kWh. However, cost of solar in Thailand is a much closer to grid electricity price than the U.S. This is a good sign for developing solar PV in Thailand since it will achieve grid parity soon.

As stated earlier that Bangkok residents might not be able to install solar PV with current installed cost and operating cost due to their limited income. However, their relatively high savings and the relatively close costs of solar compared to grid electricity could be factors that encourage them to install PV. Still, some incentives and policies might be needed to decrease costs of solar energy in Thailand because incomes are relatively low. To illustrate this point, as shown in Table 4.2, the U.S.'s subsidized prices of solar PV for both scales are much lower than LCOE without any incentives. Furthermore, subsidized prices are much closer to grid electricity price more than unsubsidized solar prices. It is also possible that subsidized prices might be either lower or equal to grid electricity price if the government gives enough incentives for decreasing costs of solar energy.

For solar policies and incentives in Thailand, as discussed in Chapter 2, currently, the Thai government has used the Feed-in Tariff (FiT) to support solar PV installation. More analysis related to incentives and policies of solar PV for both residential scale and large scale will be described in the next chapter.

4.3.2 Relate to Income and Expense

Expenses and Savings as a % of Income		Residential scale	Large scale (Mfg.)	Large scale (Hotel)
Monthly Income or Revenue (USD)		1,153	43,038	59,689
Grid	Expenses (%)	72	78	50
	Saving or Profit (%)	**28**	**22**	**50**
	Electricity Expenses (%)	4	2	12
PV	Expenses (%)	74	79	54
	Saving or Profit (%)	**26**	**21**	**46**
	Electricity Expenses (%)	6	3	19

Table 4.3: Income and Expense Analysis.

(Adapted from National Statistical Office, 2014; National Statistical Office, 2003)

The objective of this section is to understand how much money is needed to fund residential solar PV. As discussed at the beginning of this chapter, for residential scale, monthly expenses are account for 72 percent of income, so saving is normally 28 percent of income. Assuming residential income and all expenses are constant, except for electricity expenses, if the resident plans to install solar PV, they need to pay for electricity expenses more than usual due to the fact that cost of solar energy is more expensive than retail electricity grid price. In Table 4.3, the percentage of electricity expenses (from solar PV) is 6 percent of income, which increase 2 percent from grid-based. Consequently, considering electricity from solar PV, monthly saving of each household decreases from 28 percent to 26 percent. It means that only 2 percent of household income, out of 28 percent saved, is needed to fund residential solar PV in Bangkok. Therefore, because residential consumers generally save their income, they should have enough money to invest in solar PV.

As for large scale (Table 4.3), manufacturing normally, makes profit 22 percent of income and spends on electricity expenses around 2 percent. If they try to install solar PV, electricity expenses will increase to be 3 percent of income and their profit will decrease to be 21 percent. Comparing to hotels, another example of large scale user, normally, hotels use a lot of electricity per month, which cost approximately 12 percent of their income; however, they generally make profits around 50 percent, which is much more than manufacturing does. Changing from grid electricity to solar PV will affect their electricity expenses by increasing 7 percent of their expenses each month and also decreasing their profits to be 46 percent of income. Thus, it is concluded that only 1 out of 22 percent saved and 4 out of 50 percent saved of income, is needed to fund solar PV for manufacturing and hotel, respectively. As same as residential scale, these examples of large scale consumer usually make high profits that might be able to spend on installing solar PV.

4.4 Economic Analysis Summary

Solar PV, normally, has a high installed cost, but low operating cost when compared to other different power generators. The installed cost of solar PV in Thailand is lower than in the U.S. due to the lower labor cost and solar cell cost. Focusing on solar PV in Thailand, as for residential scale, the installed cost is 1.88 US$ per kW, while large-scale's installed cost is 1.72 US$ per kW. The operating cost of PV for both residential and large-scale is assumed at 0.01 US$ per kWh.

Considering LCOE of both scale in Thailand and the U.S., it is higher than grid electricity price. For Bangkok, residential LCOE calculated from the PVWatts is 0.14 US$ per kWh, while large –scale solar PV has a LCOE of 0.13 US$ per kWh. To be economically viable, the project's LCOE must be equal to or less than the average retail electricity rate. Then, some incentives and policies are needed to decrease costs of solar energy in Thailand.

In order to understand the economics of consumers, expenses and savings per month are discussed to compare costs of energy between grid and solar PV. Per residential scale, the percentage of electricity expenses increases from 4 percent (grid-based) to 6 percent (solar PV-based) of their income. Consequently, monthly saving of each household decreases from 28 percent to 26 percent if they decide to install solar PV. It means that only 2 percent of household income, out of 28 percent saved, is needed to fund residential solar PV in Bangkok. According to large scale, changing from grid electricity to solar PV will affect their electricity expenses by increasing 1 percent and 7 percent of their expenses for manufacturing and hotel, respectively and also decreasing their profits to be 21 percent of their income for manufacturing and 46 percent of their income for hotels. Thus, only 1 out of 22 percent saved and 4 out of 50 percent saved of income, is needed to fund solar PV for manufacturing and hotel, respectively. Both residential scale and large scale consumers generally should have enough savings or profits to invest on solar PV project.

However, even if both residential scale and large scale seem to have enough saving and profit, they might not be interested in solar PV installation due to the higher solar costs than grid electricity. Therefore, it is very important to use financial incentives (discussed in the next Chapter), such as tax credit, along with FiT to increase solar PV installation rates in Bangkok. Different policies might be suitable with different group of people. For instance, tax credit seems to be appropriate with high income tax payers, who might be interested in reducing their tax payments, while low income tax payers might be interested in FiT or low interest rate loans since they needs these incentives to reduce capital costs for solar PV investment.

Chapter 5: Policy Analysis

This chapter discusses the policy analysis of residential solar PV in Bangkok. The first part (Section 5.1) of this chapter reviews the current solar incentives in Bangkok. The second part (Section 5.2) summarizes the methodology of cash flow evaluation and financial analysis that used to evaluate the current incentives in Bangkok. The project's cash flow and financial analysis results are shown in the third part (Section 5.3). In Section 5.4, policy suggestions are summarized and compared to countries that have successfully increased the adoption of solar PV, and thus could provide a model for Bangkok or Thailand overall. The overview of barriers for Thailand's solar PV development is presented in Section 5.5 in order to understand why policies and incentives are necessary. Finally, in Section 5.6 concludes with the policy analysis of solar PV in Bangkok to point out the main idea.

5.1 Introduction

Based on Fig. 5.1, the Thai government started the solar policy and support schemes in 2006. Thailand's utility scale renewable energy sector was first supported under an Adder scheme starting in 2007. With the Adder scheme Thailand's state owned electricity distributors offered to buy electricity from renewable energy producers, including solar producers, under Power Purchase Agreements (PPAs) by paying "Adder" (equals to 0.24 US$/kWh) on top of the wholesale electricity price as shown in Equation 5.1.

$$\text{Electricity Purchase price} = \text{Electricity Wholesale price} + \text{Adder} \tag{5.1}$$

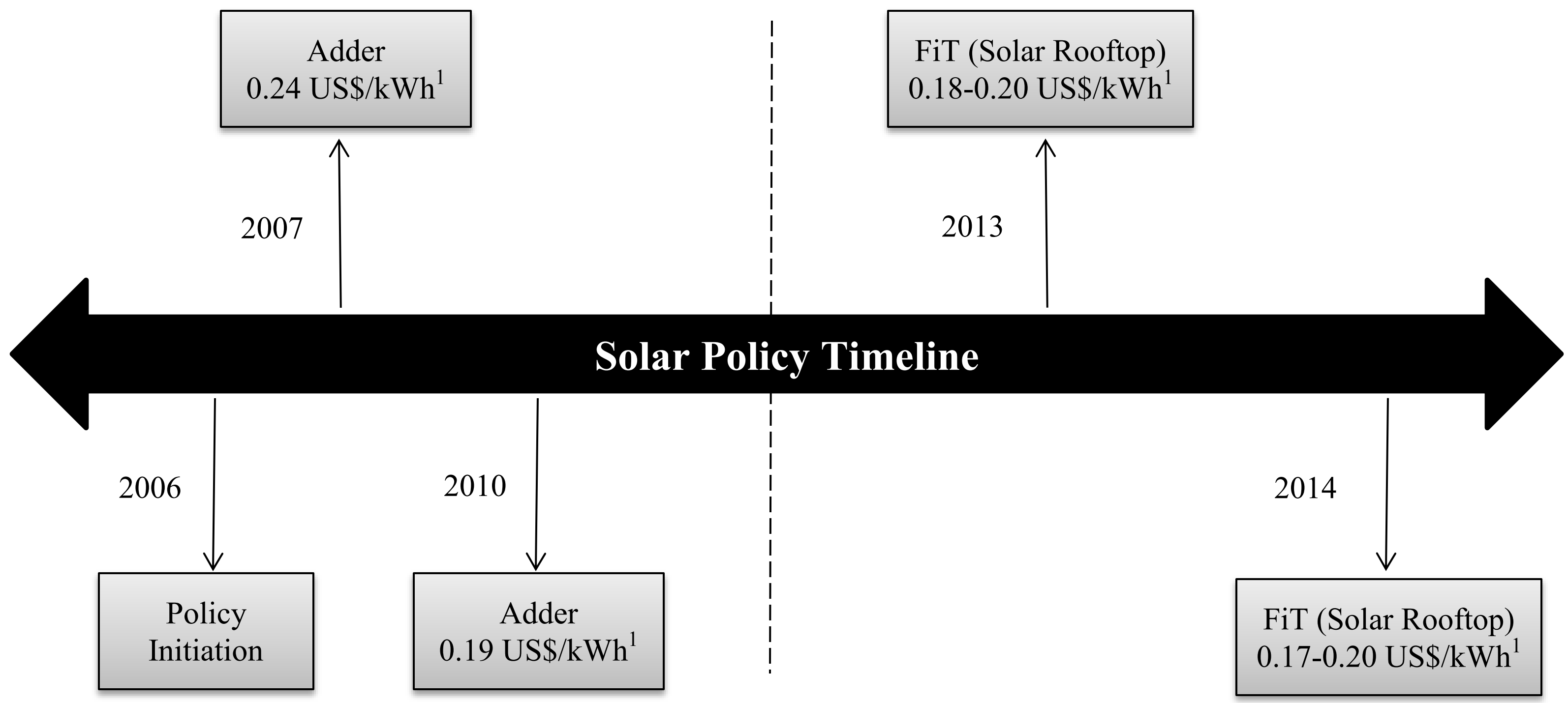

Figure 5.1: Solar Policy Timeline in Thailand (Adapted from Tongsopit, 2015)[1]

[1] The exchange rate 33.8 Baht/US$, as of 6/1/2015 from Siam Commercial Bank

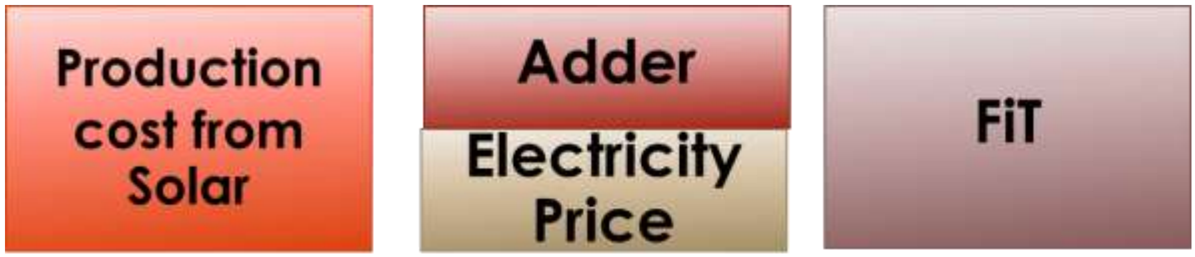

Figure 5.2: Adder vs. FiT

In 2010, focusing on solar energy, the adder rate changed to 0.19 US$/kWh, and also in that year, the National Energy Policy Commission (NEPC) planned to replace the support scheme from the Adder to a Feed-in Tariff (FiT), which is a fixed amount per kWh paid during the life of PPAs, for Very Small Power Producers (VSPPs) - power producers generating less than 10 MW. The reasons for discontinuous support of the solar Adder were the oversubscription of this Adder program and regulators 'concerns on the impact of electricity pass-through costs to consumers (Tongsopit and Gracen, 2013).

In Fig. 5.2, the difference between Adder and FiT is summarized. As stated earlier, Adder is the support scheme paying on top of the wholesale electricity price that based on fuel prices, while FiT is a fixed amount per kWh paid during the life of project. At that time, the NEPC believed that FiT could help solar PV to achieve grid parity very soon. The FiT was first implemented in Thailand in 2013. The FiT rate is different based on the producer's capacity. As mentioned in Chapter 2, currently, the FiT rate in Thailand, depending on the installed capacity (residential, commercial, and large-scale rooftop), is between 0.17-0.20 US$/kWh.

Furthermore, FiT has been effective in many countries in the world, especially the countries in Europe, such as Italy, Spain, Germany and France. Fig. 5.3 presents the percentage of change in annual solar installation levels in four countries after setting up a FiT mechanism. All four countries increased their installation by more than 150 percent.

According to Thailand, as discussed in Chapter 2, after FiT implemented, NEPC decided to move the target forward from 3,000 MW to 3,800 MW. This is a good sign for increasing solar PV implementation in Thailand. Nonetheless, people still debate if the FiT is too expensive, even it can boost solar installation rate.

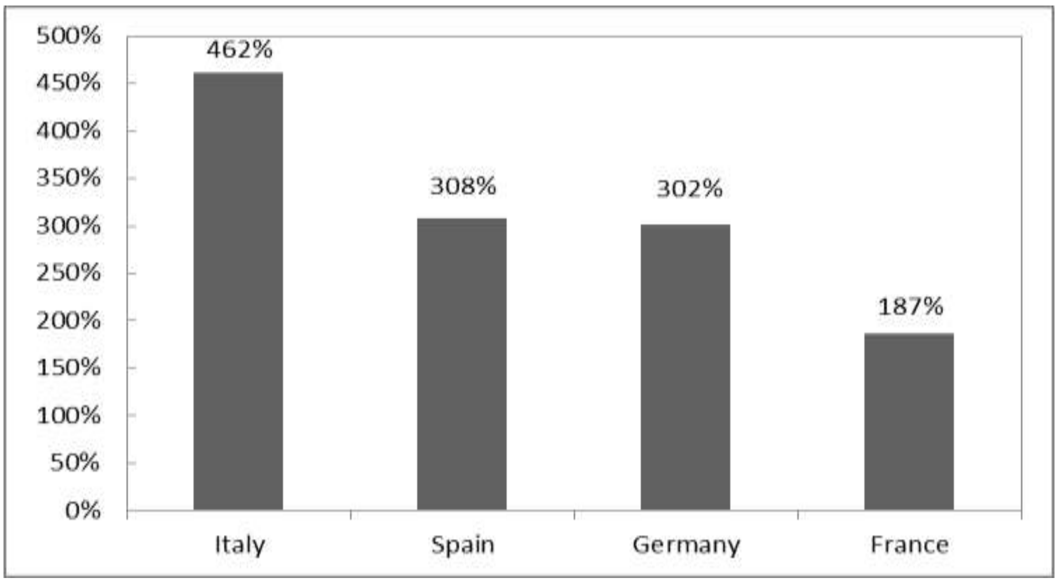

Figure 5.3: Percentage Change in Annual Solar Installation Levels in Two Years of Four Countries after Setting up a FiT Mechanism (Chaianong and Pharino, 2015)

5.2 Methodology

The PVWatts in SAM is used in this policy analysis section to analyze project's cash flow and financial parameters, including Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP) in order to better understand whether a solar PV incentives are needed to make costs of residential PV equal to, or less than the residential electricity price, or reaching grid parity.

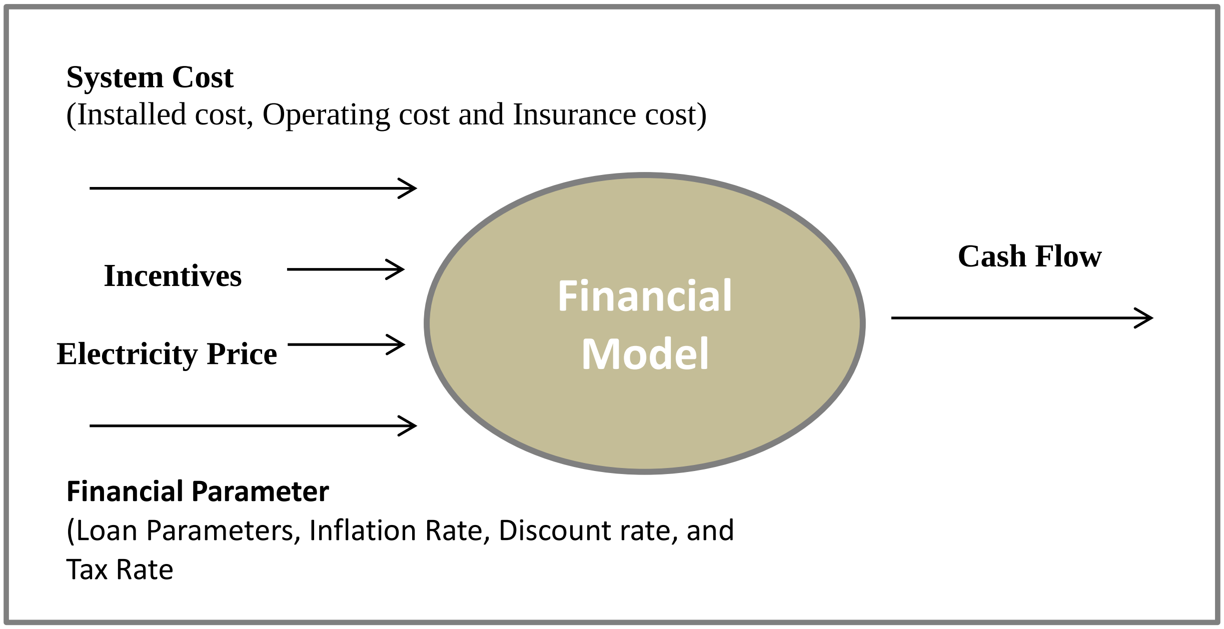

Figure 5.4: SAM Financial Model Diagram (Adapted from Gilman, 2015).

As shown in Fig. 5.4, there are four major types of input needed for the cash flow model in order to calculate cash flow and financial parameters, as mentioned above. System cost (installed cost, operating cost, and insurance cost), incentives, sell and buy electricity price (to calculate value of energy generated), and financial parameters, such as loan parameters, inflation rate, and tax rate. As stated in the previous chapter, the project's lifetime is assumed to be 25 years. The buy electricity price is assumed to be 0.12 US$/kWh for both scales. Additionally, the details of other parameters used in the PVWatts are summarized in Table 5.1.

System Parameters	Residential Scale	Large Scale	References
System Cost			
Installed Cost ($/W)	1.88	1.72	Kasetsart University, 2012 and Kurovat, 2014
Operating Cost ($/kWh)	0.01	0.01	Tongsopit, 2014
Operating Cost Escalation Rate (%)	3	3	Dobos, 2014 and Gilman, 2015
Insurance Cost (% of installed cost)	0.5	0.5	Tongsopit, 2014
Financial Parameter			
Debt Fraction (%)	50	50	Tongsopit, 2014
Loan Term (Years)	8	8	Tongsopit, 2014
Loan Rate (%/year)	6.15	5.00	Tongsopit, 2014 and KrungThai Bank
Income Tax Rate (%/year)	10	15	Angloinfo, undated and Tongsopit, 2014
Nominal Inflation Rate (%)	2.8	2.8	World Bank, 2014
Discount Rate (%)	3	3	Index Mundi, 2014
Incentives (the sell electricity price)			
FiT ($/kWh)	0.20	0.18	Federal Ministry for Economic Affairs and Energy, and Energy Research Institute, 2015

Table 5.1: Cash Flow and Financial Parameter Calculation Input Summary.

5.2.1 Cash Flow Analysis

Cash flow depends on many factors indicated in Table 5.1. The cash flows are taken as the sum of all the costs and profits in any year using the following:

- Year 0:

  Investment cost = (Installed cost – Investment-based incentives) × Debt fraction (5.2)

- Year 1-25:

  Pre-tax cash flow (Payment) = Operating cost + Principal + Interest payment + Insurance cost (5.3)

  After-tax cash annual cost = Incentive income - Pre-tax cash flow - Tax on incentive income + Tax credit (5.4)

  After-tax value of energy generated[2] = (Value of energy per kWh) × kWh of energy generated) (5.5)

  After-tax cash flow = After-tax cash annual cost + After-tax value of energy generated (5.6)

5.2.2 Financial Parameter Calculation

In this analysis, three financial parameters are calculated to evaluate the feasibility of solar PV installations in Bangkok: Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP).

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[2] For with incentive case, SAM calculates this value on an hourly basis. For hours when PV generates more electricity than the load consumption, SAM sells the excess electricity at the sell rate (FiT rate). On the other hand, when PV generates less electricity than the load demand, SAM buys the extra electricity from the grid at the buy rate (0.12 US$/kWh). FiT is assumed to be available for all excess electricity.

For without incentive case, the buy rate is 0.12 US$/kWh, while the sell rate is 0 US$/kWh.

5.2.2.1 Net Present Value (NPV)

The net present value (NPV) is one parameter that can indicate the project's economic feasibility by considering both value of energy savings and project's cost under discounted rate condition as illustrated in Equation 5.7.

$$\mathrm{NPV} = \frac{\sum_0^n \mathrm{C_n}}{(1 + \mathrm{d_{nom}})^n} \tag{5.7}$$

Where:

NPV is net present value (US$).

C_n is after-tax cash flow in Year n from Equation 5.5.

d_{nom} is nominal discount rate (considering inflation rate).

n is analysis period (25 years).

According to Short *et al.* (1995), NPV analysis is usually used when valuing the feasibility of investment before making a decision between mutually exclusive projects. Generally, a positive NPV means a profitable and economically feasible project, while a negative NPV indicates a net loss of infeasible project.

5.2.2.2 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the rate that sets the NPV of the cash flows equal to zero. As same as NPV, IRR is also used to compare investment activities in terms of accepting or rejecting decisions by allowing a quick comparison with a minimum acceptable rate of return (Short *et al.*, 1995). The Equation for IRR calculation is described below.

$$\mathrm{NPV} = \frac{\sum_0^n \mathrm{C_n}}{(1+\mathrm{IRR})^n} = 0 \tag{5.8}$$

Where:

NPV is net present value (US$).

$\mathrm{C_n}$ is after-tax cash flow in Year n from Equation 5.5.

IRR is internal rate of return.

n is analysis period (25 years).

5.2.2.3 Payback Period (PBP)

The payback period (PBP) is the time in years that required recovering the cost of investment (NPV equals zero). If the project takes a longer payback period, it is normally not feasible and desirable for an investment. There are two ways to reduce the payback period: Decrease the installed cost (or increase investment-based incentives), and decrease operating costs (or increase project tax savings). In the PVWatts, the payback period is calculated using non-discounted cash flow, summarized below.

- Year 0:

  Cash flow for PBP = Installed cost – Investment-based incentives (5.9)

- Year 1-25:

  Cash flow for PBP = After-tax cash flow + Principal payment + Interest payment (5.10)

Cash flow for payback period calculation does not consider discounted rates and loan payments, so there are some minor changes of cash flow used in the payback period calculation and the Equation for payback period is shown below.

$$NPV = \frac{\sum_0^n C_n}{(1 + d_{nom})^{PBP}} = 0 \qquad (5.11)$$

Where:

NPV is net present value (US$).

C_n is after-tax cash flow in Year n from Equation 5.5.

d_{nom} is nominal discount rate (considering inflation rate).

PBP is analysis period that let NPV equals to zero.

5.3 Results

5.3.1 Residential scale

5.3.1.1 Cumulative After-tax Cash Flow

Per technical inputs in Chapter 3, the cash flow and all financial parameters are calculated based on 3,000 MW solar PV's capacity in Bangkok. Fig. 5.5 and 5.6 shows the annual after-tax cash flow and cumulative after-tax cash flow of residential solar PV without incentives, respectively. These cash flows consider a discount rate and a loan payment. The total installed cost is around 6,000 million US$. Thus, if considering 50% loan, in year zero the investment cost is approximately 3,000 million US$. The cumulative cash flows are more negative in the first 8 years, which is the loan period. Accordingly the annual cash flows in Fig 5.5 for the first 8 years are still negative since practically all of the value of energy generated cannot offset by the loan payment. After the loan period, the cumulative cash flow is less negative and become positive because of a net value from energy generated. The details of these cash flows are presented in an Appendix.

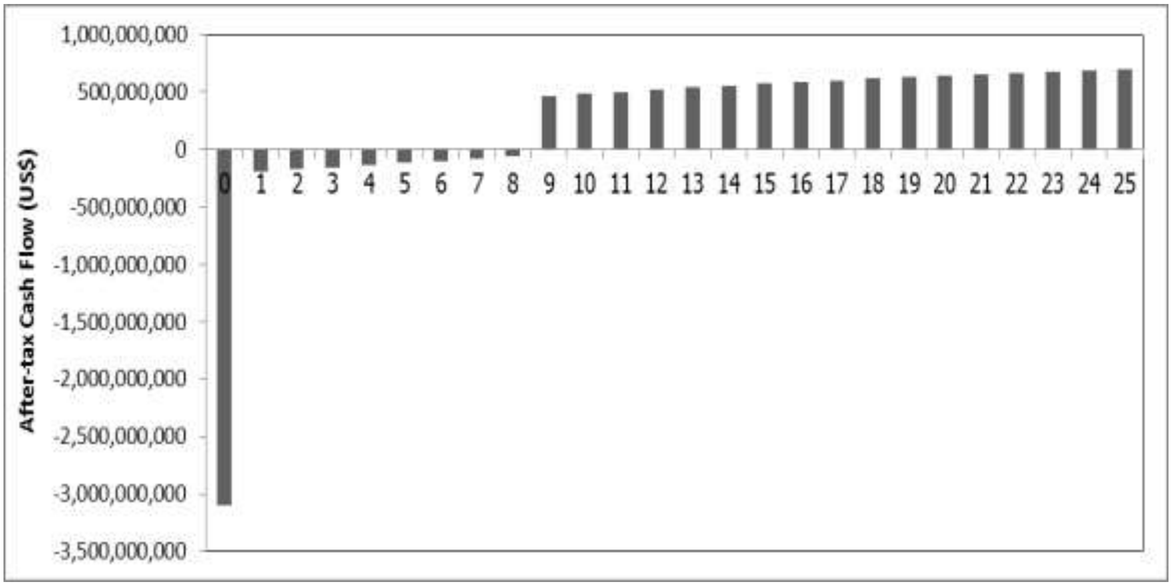

Figure 5.5: After-tax Cash Flow of Residential Solar PV Project

(Without incentives).

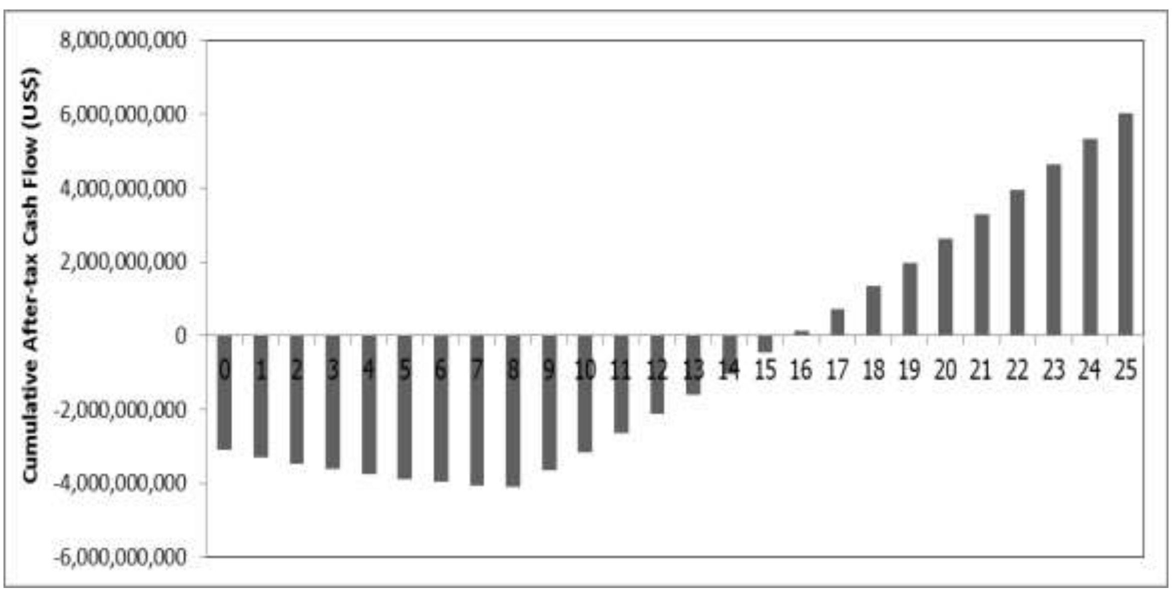

Figure 5.6: Cumulative After-tax Cash Flow of Residential Solar PV Project

(Without incentives).

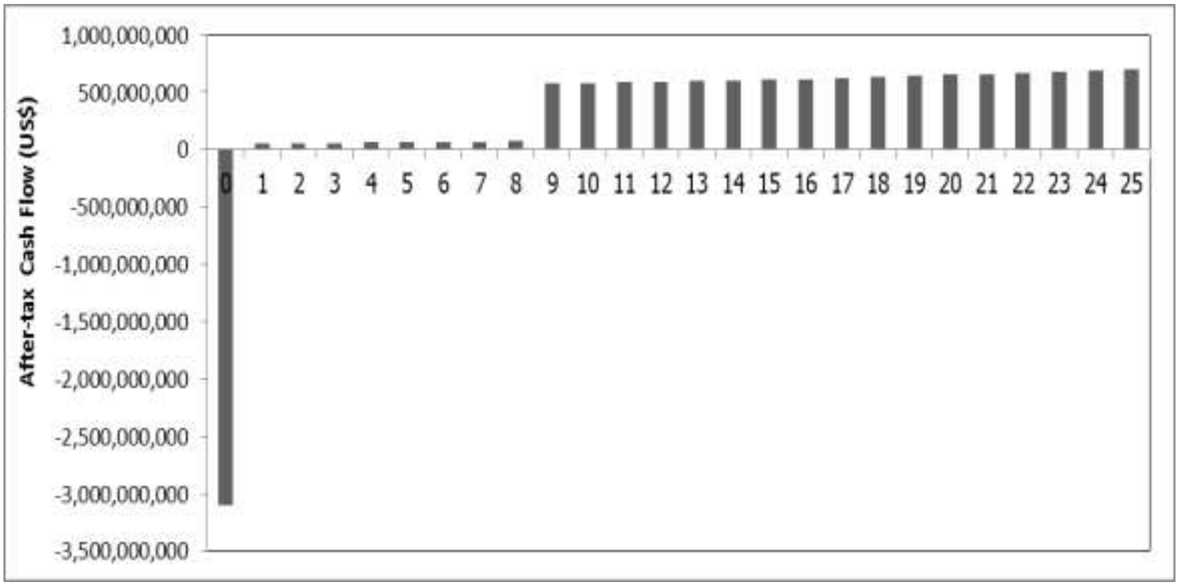

Figure 5.7: After-tax Cash Flow of Residential Solar PV Project

(With incentives- FiT rate is 0.20 US$/kWh).

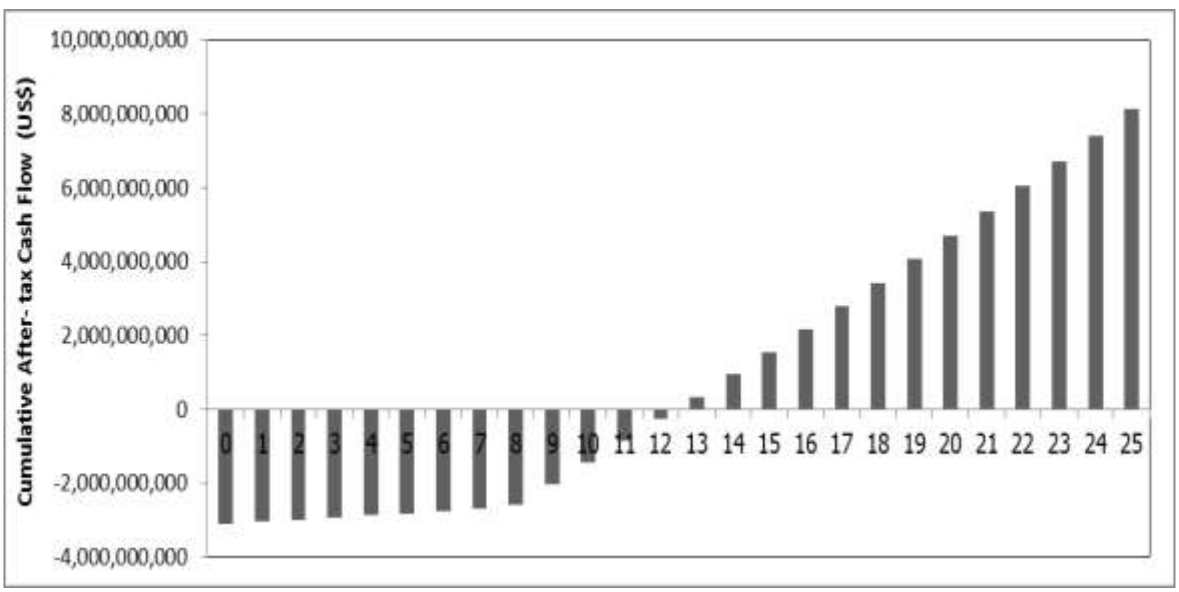

Figure 5.8: Cumulative After-tax Cash Flow of Residential Solar PV Project

(With incentives- FiT rate is 0.20 US$/kWh).

When including the current solar incentive for residential scale, a FiT equals to 0.2 US$/kwh, the annual cash flow and the cumulative cash flow are summarized in Fig. 5.7-5.8, respectively. The investment cost in year zero is approximately 3,000 million US$, the same as the case with no incentives. Unlike the without incentives case, due to the FiT schemes, the single annual cash flow (Fig. 5.7) in year 1 onwards has a positive value because selling the excess electricity back to the grid provides annual revenues that exceed the yearly loan payment. Moreover, the cumulative after-tax cash flow (Fig. 5.8) becomes positive faster before the end of the project period. It is noticeable that the current FiT incentive appears financially effective to help promote solar PV in Bangkok.

5.3.1.2 Financial Analysis

As mentioned earlier, NPV and IRR are calculated based on cumulative after-tax cash flows (Fig. 5.6-5.8), while PBP is considered from cash flows that do not include a discount rate and a loan payment. For the case without incentives, Fig. 5.9 and 5.10 shows the annual and the cumulative cash flow for simple PBP calculation, respectively. During the first 8 years (loan period), the cumulative cash flow (Fig. 5.10) increases continuously over time, corresponding with annual cash flows in Fig. 5.9 that each have approximately the same positive value, unlike when the analysis considers loan payments (see Fig. 5.5-5.6).

For the incentive case in Fig. 5.11-5.12, the main difference from Fig. 5.7- 5.8 is the cumulative cash flow for a single year is not discounted and does not consider a loan payment. Each annual cash flow (Fig.5.11) is positive at approximately the same value that is higher than in the case without the FiT incentive. The LCOE is calculated as discussed in Equation 4.1. The results do not include any information about incentives.

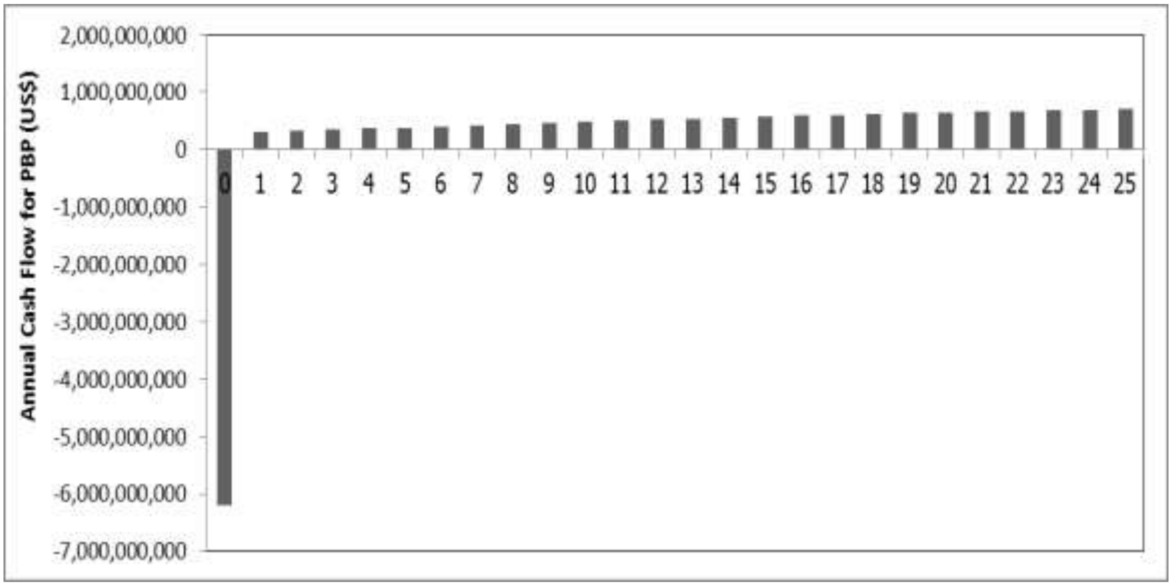

Figure 5.9: Annual Cash Flow of Residential Solar PV Project for PBP calculation (Without incentives).

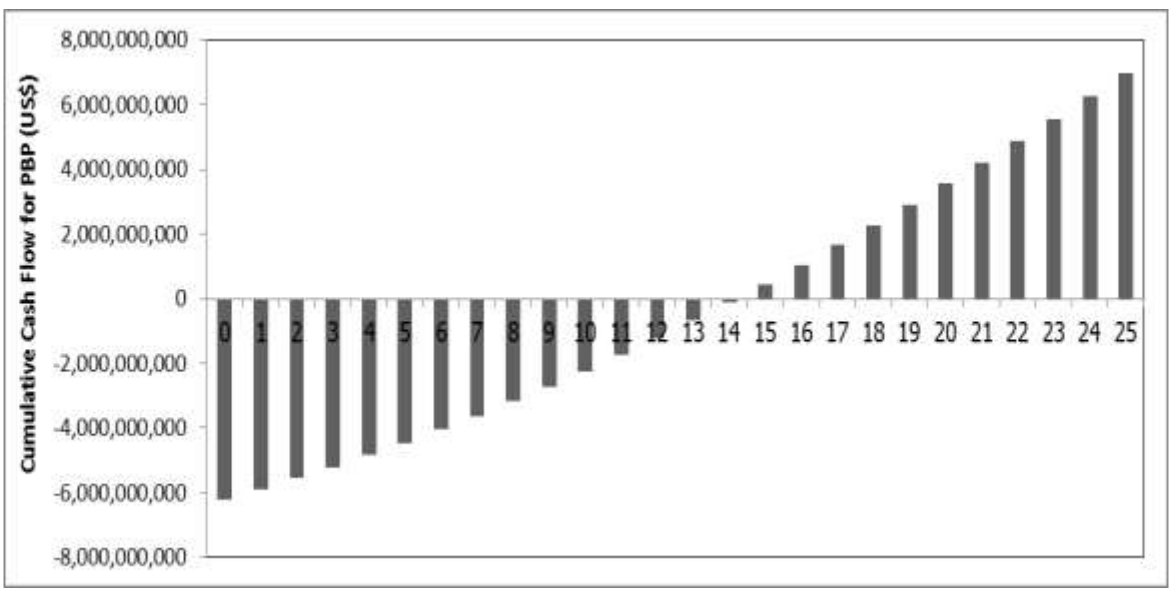

Figure 5.10: Cumulative Cash Flow of Residential Solar PV Project for PBP calculation (Without incentives).

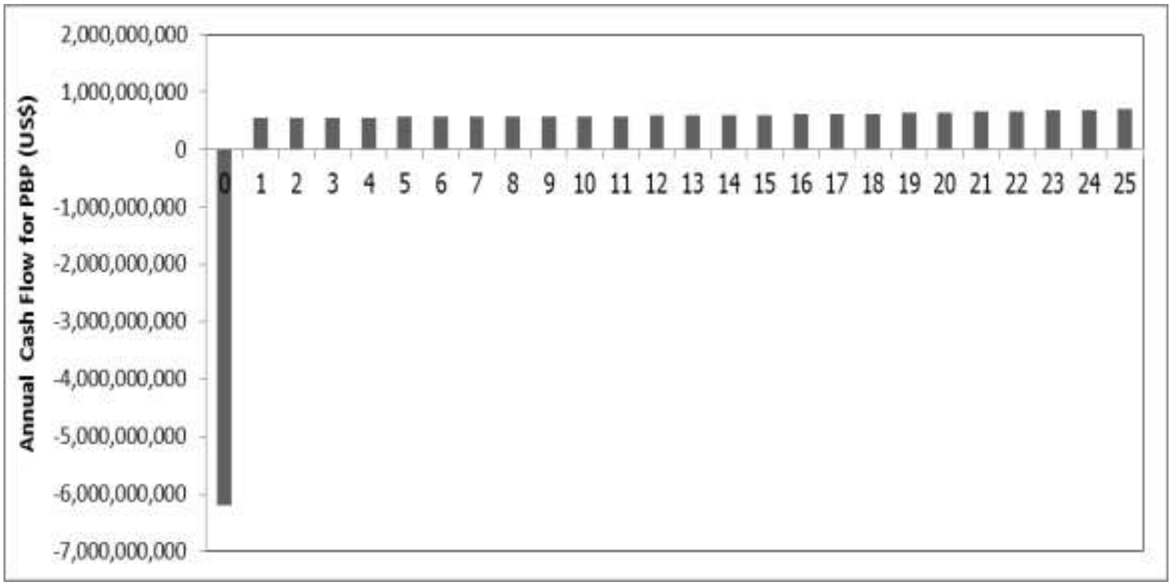

Figure 5.11: Annual Cash Flow of Residential Solar PV Project for PBP Calculation

(With incentives- FiT rate is 0.20 US$/kWh).

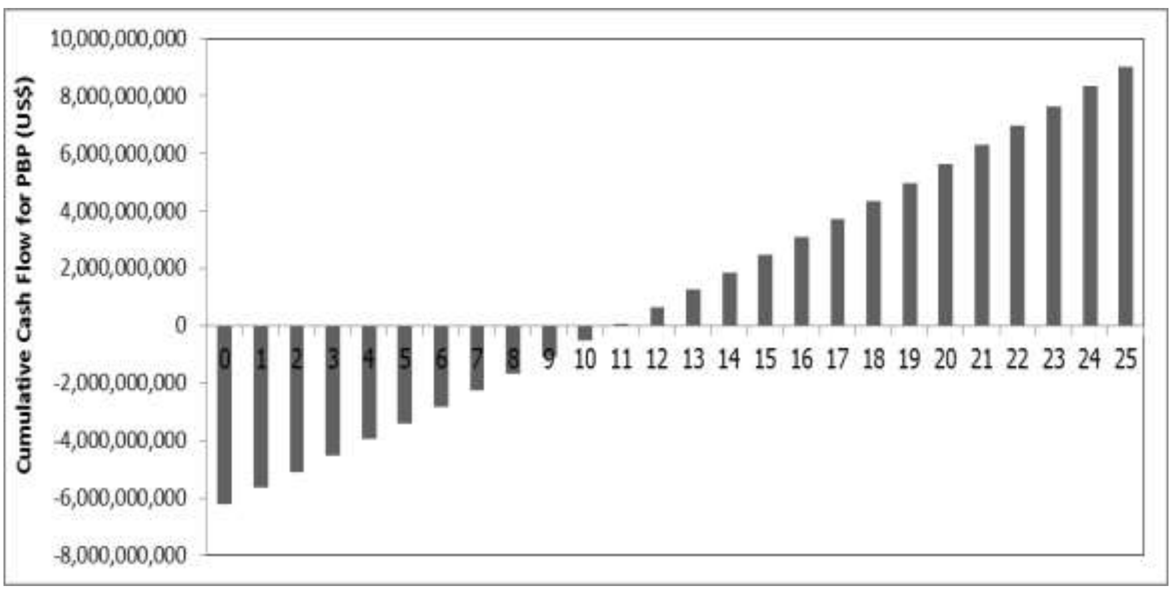

Figure 5.12: Cumulative Cash Flow of Residential Solar PV Project for PBP Calculation

(With incentives- FiT rate is 0.20 US$/kWh).

Financial Parameter	Without Incentives	With Incentives (FiT = 0.2 US$/kWh)
NPV (US$/kWh)	-0.0006	*0.01*
IRR (%)	6	*8.7*
PBP (Years)	14.21	*10.88*
LCOE (US$/kWh)	0.14	*0.14*

Table 5.2: Financial Analysis Summary for Residential Scale.

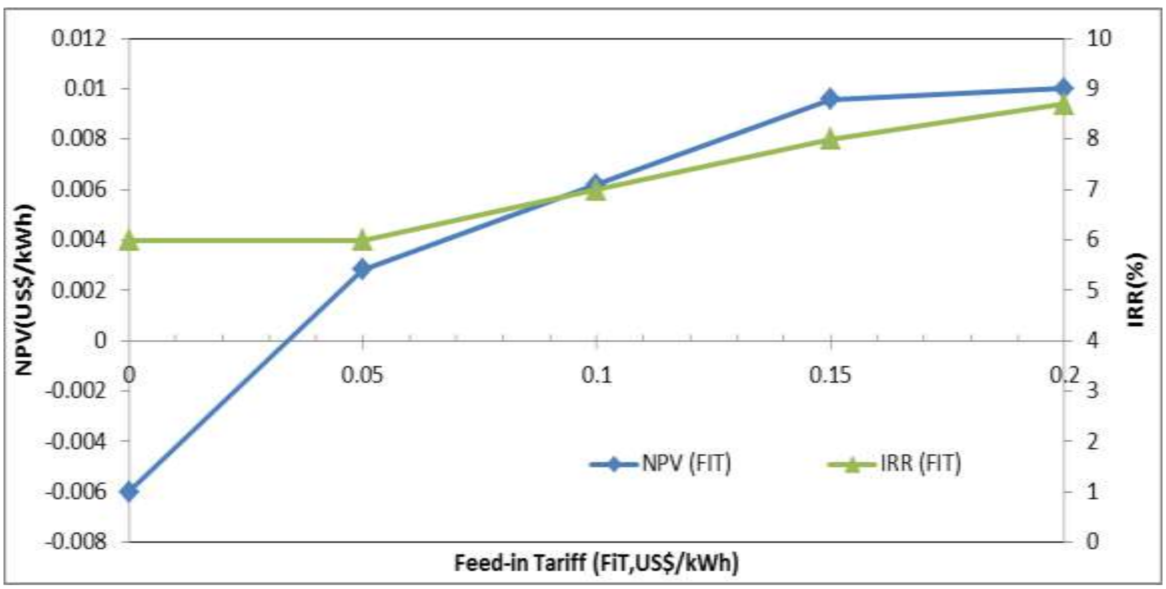

Figure 5.13: The Relationship between NPV, IRR and FiT of Residential Scale.

As seen in Table 5.2, with the FiT of 0.2 US$/kWh, the NPV increases from -0.0006 to 0.01 US$/kWh, and the IRR rises from 6 to 8.7 percent, while PBP decreases from 14.2 to 8.9 years. The difference of financial parameters in these two cases results from the excess electricity that can be sold to the grid in order to receive FiT. NPV, IRR and PBP of residential scale solar PV under the parameter assumptions (See Table 5.1) indicates whether solar projects with incentives seem to be feasible in Bangkok compared to other investment methods such as zero coupon bond (25 years) that provides an IRR equal to 3.88% (BMA-Thai Bond Market Association, 2015). Based on Fig. 5.13, the FiT for residential scale could be less than 0.2 US$/kWh in order to enable a more positive NPV and higher IRR as compared to other types of investment (e.g. zero coupon bond).

5.3.2 Large scale

5.3.2.1 Cumulative After-tax Cash Flow

In this part, the solar capacity assumption is the same as in the analysis of residential scale except loan rate. In large scale, loan rate is less than residential scale as shown in Table 5.1. As same as residential scale, the annual and the cumulative cash flows in Fig. 5.14 and 5.15 consider a discounted rate and a loan payment as summarized in Table 5.1. Since the installed cost per kW of large-scale solar PV is less than residential solar PV, the total installed cost is around 5,600 million US$, 10 percent lower than for residential scale.

Considering a loan payment, in year zero, the investment cost of large-scale is approximately 2,800 million US$ (debt fraction is 50 percent.). From Fig. 5.15, the cumulative cash flows are nearly the same amount (about 2,800 million US$) in the first 8 years, which is the loan period, because the annual cash flow (Fig 5.14) is nearly zero during the first 8 years as the value of the PV electricity roughly offsets the loan payment. After the loan period, the cumulative cash flows are less negative and become positive faster than residential scale. The details of these cash flows are also described in the Appendix.

The trends of large-scale cumulative after-tax cash flow with FiT are the same as in the case of the residential installation. The annual cash flows are positive for all years except during the year of installation (Fig. 5.16) such that the cumulative cash flow becomes positive in approximately 12 years (Fig. 5.17).

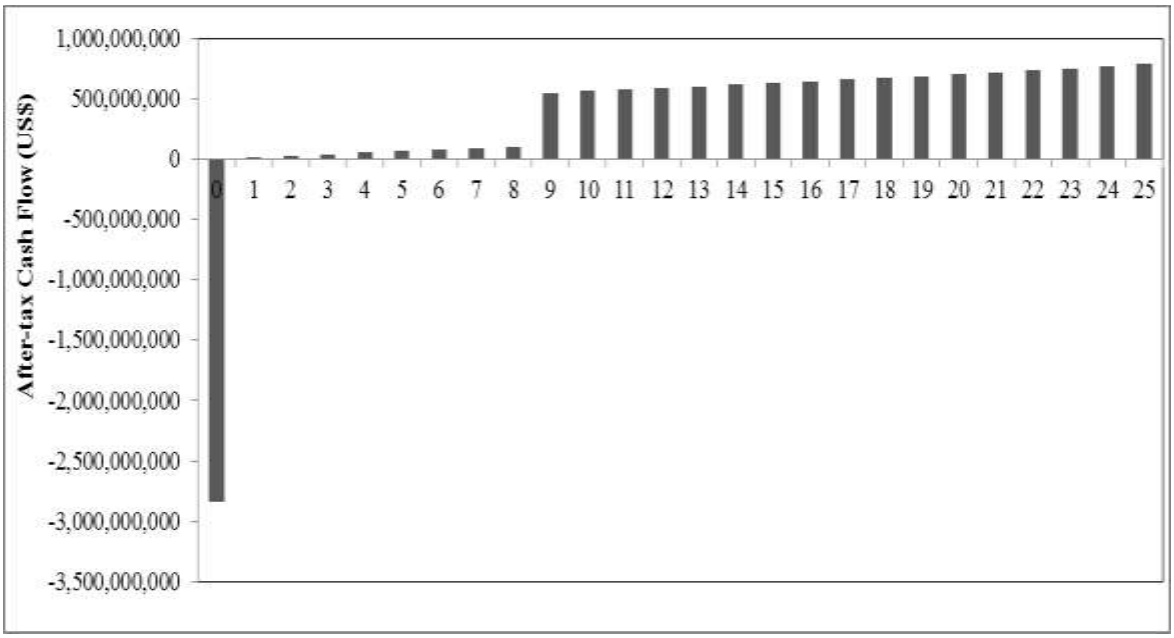

Figure 5.14: After-tax Cash Flow of Large-scale Solar PV Project

(Without incentives).

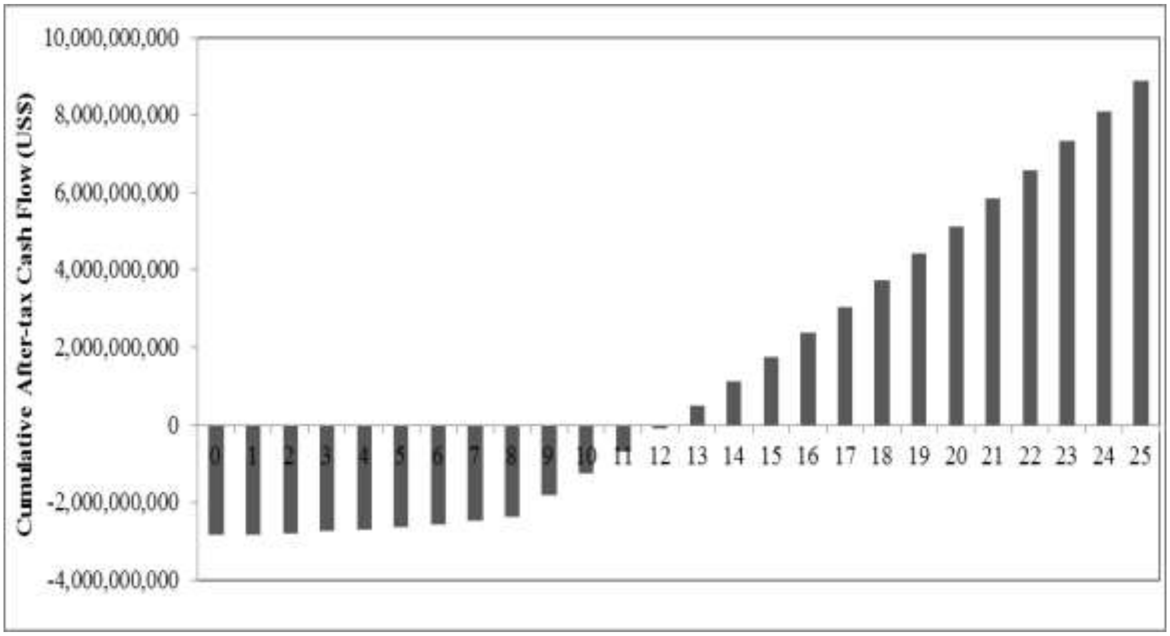

Figure 5.15: Cumulative After-tax Cash Flow of Large-scale Solar PV Project (Without incentives).

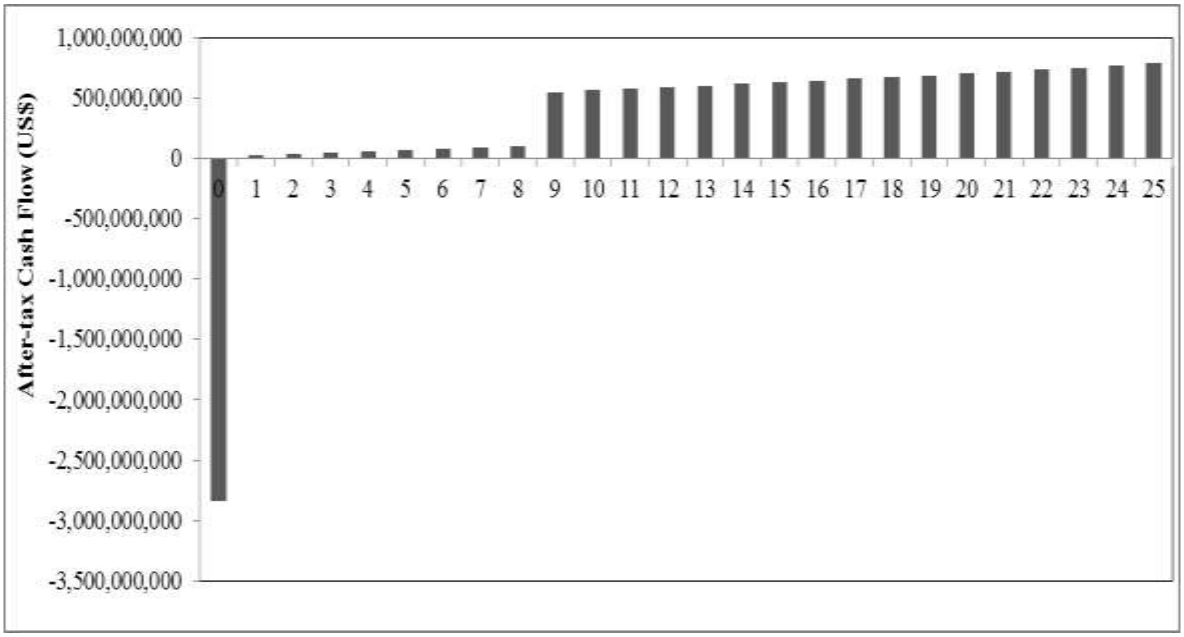

Figure 5.16: After-tax Cash Flow of Large-scale Solar PV Project

(With incentives- FiT rate is 0.18 US$/kWh).

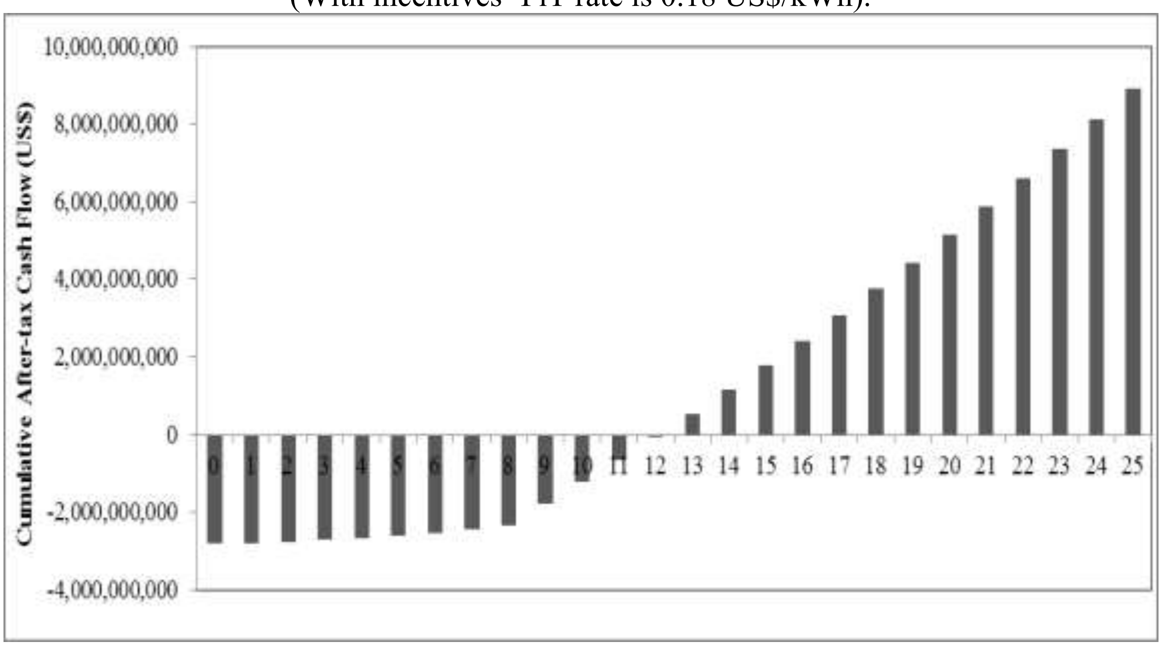

Figure 5.17: Cumulative After-tax Cash Flow of Large-scale Solar PV Project

(With incentives- FiT rate is 0.18 US$/kWh).

5.3.2.2 Financial Analysis

For large scale, NPV and IRR are calculated based on cumulative after-tax cash flows (Fig. 5.15 and 5.17), while PBP is considered from cash flows that are not included a discounted rate and a loan payment. For the case without incentives, Figures 5.18 and 5.19 present the annual and the cumulative cash flows for simple PBP calculation, respectively. The main difference of the cumulative cash flow for PBP calculation in Fig. 5.19 from the cumulative cash flow without incentive case in Fig. 5.15 is that in the first 8 years, which is a loan period, the cumulative cash flows for PBP calculation increases each year at an approximate constant rate due to the corresponding near constant annual cash flows in Fig. 5.18.

Focusing on a FiT incentive study case for PBP calculation (Fig. 5.20-5.21), the main difference of cumulative cash flows for PBP calculation from Fig 5.17 is that the cumulative cash flows used for the PBP calculation are not discounted and do not include loan payments. Additionally, as in analysis of residential scale PV, when considering the FiT incentive, the single annual cash flow for PBP calculation (Fig. 5.20) is positive starting in year 1. The LCOE of large scale in with FiT case (Fit = 0.18 US$/kWh) is calculated as discussed in Equation 4.1. The results do not include any information about incentives

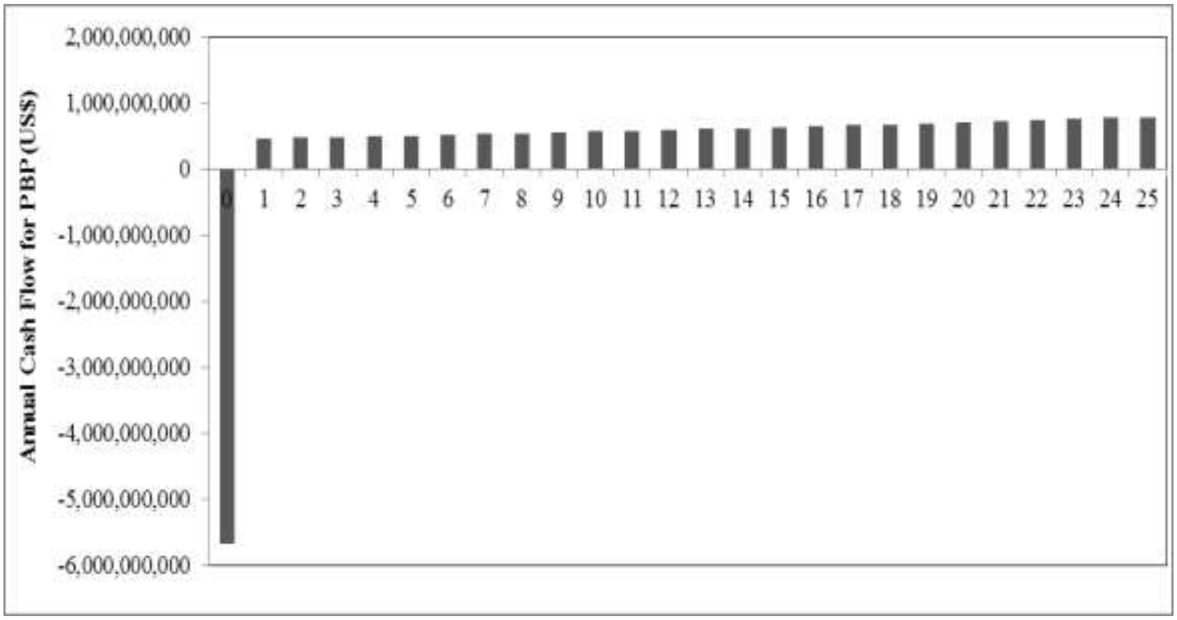

Figure 5.18: Annual Cash Flow of Large-scale Solar PV Project for PBP calculation (Without incentives).

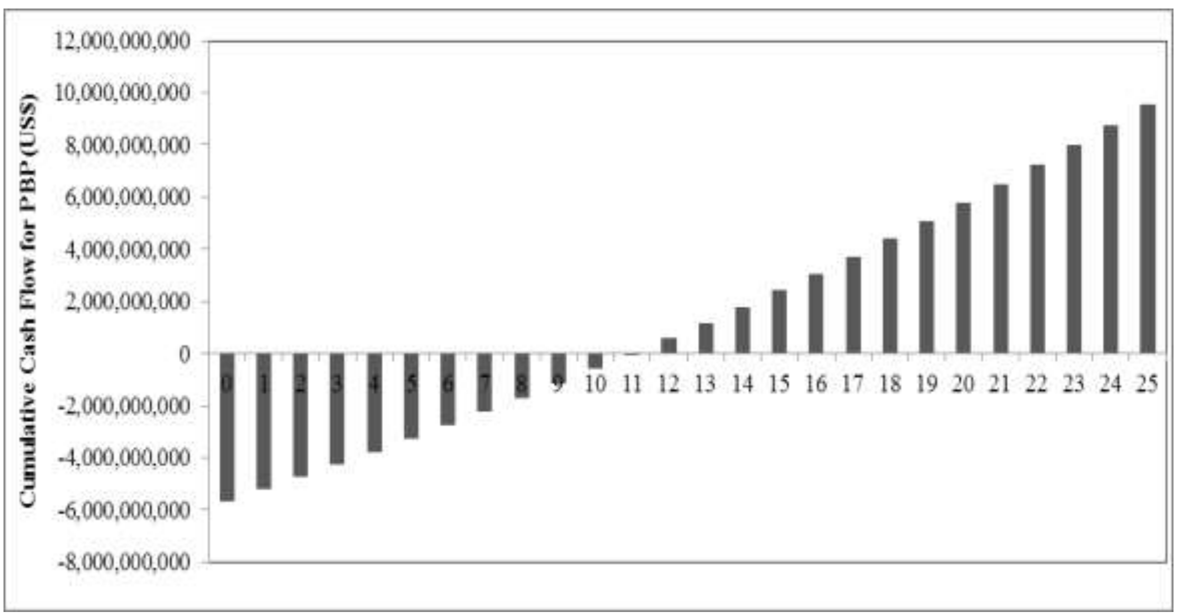

Figure 5.19: Cumulative Cash Flow of Large-scale Solar PV Project for PBP calculation (Without incentives).

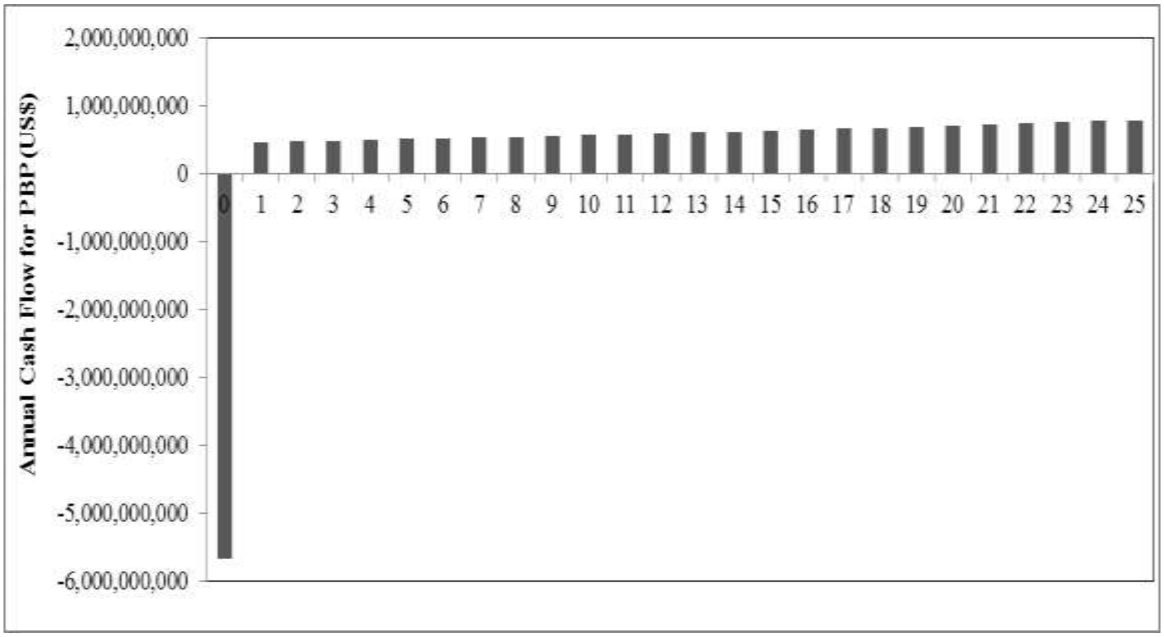

Figure 5.20: Annual Cash Flow of Large-scale Solar PV Project for PBP Calculation

(With incentives- FiT rate is 0.18 US$/kWh).

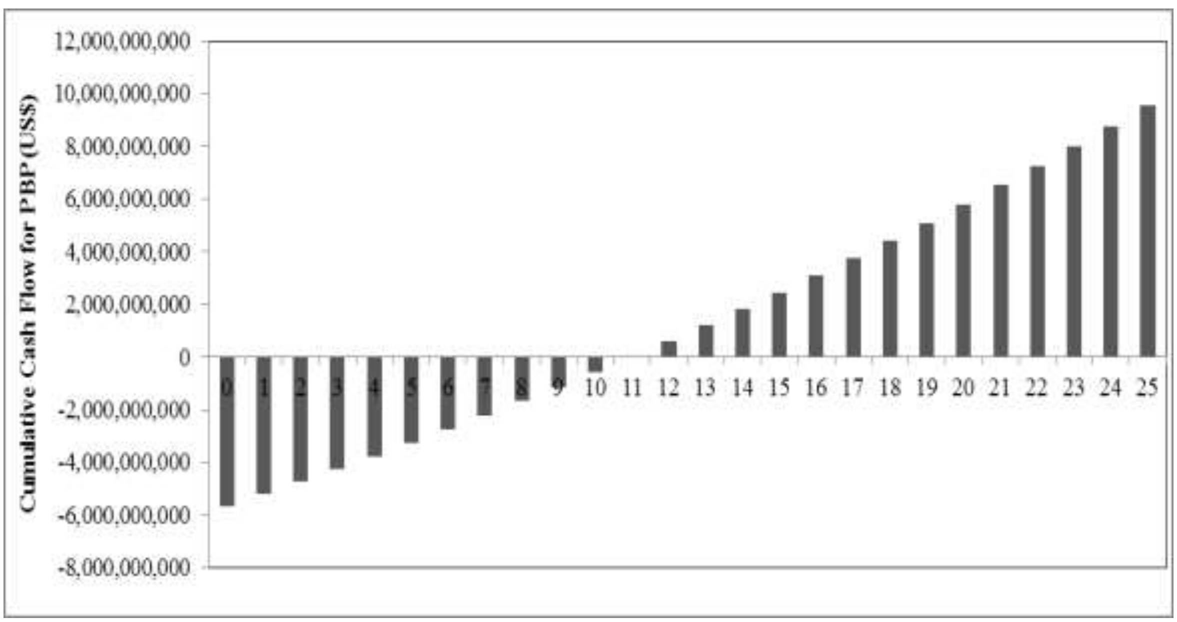

Figure 5.21: Cumulative Cash Flow of Large-scale Solar PV Project for PBP Calculation

(With incentives- FiT rate is 0.18 US$/kWh).

Financial Parameter	Without Incentives	With Incentives (FiT = 0.18 US$/kWh)
NPV (US$/kWh)	0.013	*0.017*
IRR (%)	9.4	*9.5*
PBP (Years)	11.2	*11*
LCOE (US$/kWh)	0.13	*0.13*

Table 5.3: Financial Analysis Summary for Large Scale.

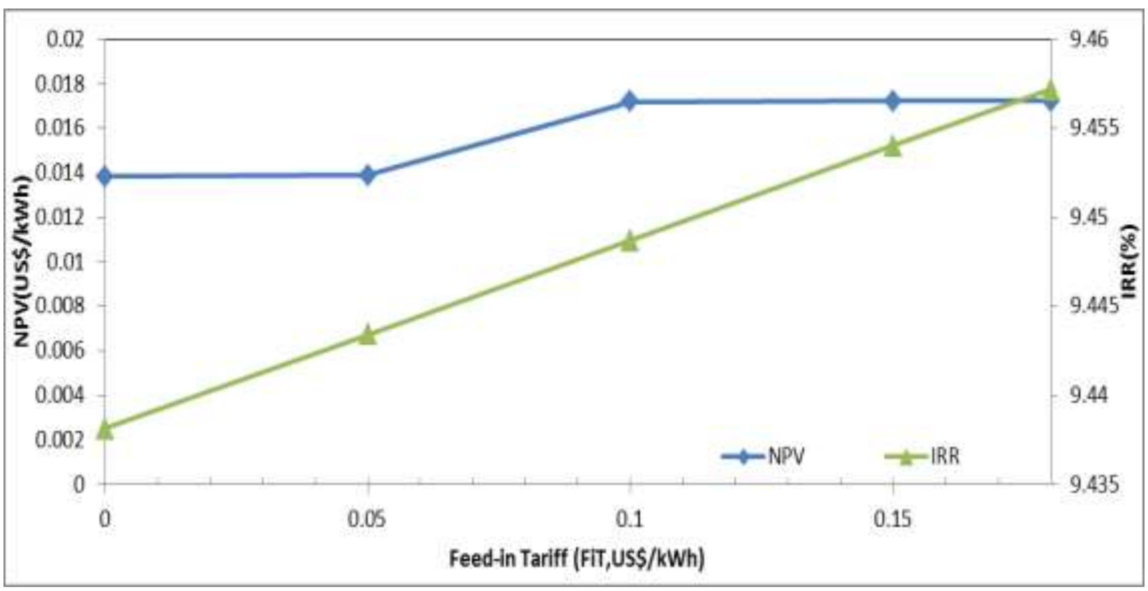

Figure 5.22: The Relationship between NPV, IRR and FiT of Large Scale.

In Table 5.3, with the FiT, the NPV increases from 0.013 to 0.017 U$/kWh and the IRR rises from 9.4 to 9.5percent, while PBP decreases from 11.2 to 11 years. It is noticeable that NPV, IRR and PBP of large-scale in both cases are slightly different due to the fact that the large-scale load patterns and distributed solar electricity patterns are well matched, thus, there are not much excess electricity to sell back to the grid in order to receive FiT, unlike residential scale. Although the higher NPV and IRR should be good for investors, Thai government might not need to offer large incentive as shown in Fig. 5.22. the FiT for large scale could be less than 0.18 US$/kWh in order to enable a more positive NPV and higher IRR as compared to other types of investment (e.g. zero coupon bond).

NPV, IRR and PBP of both residential-scale and large-scale solar PV indicates that solar projects with incentives seem to be feasible in Bangkok. Although LCOE for residential PV is higher than for large scale (e.g., industrial), Thailand's FiT makes PV equally attractive to both types of customers.

5.4 Policy Suggestions

As shown in the previous section, the current FiT scheme is an effective policy that can drive solar PV in residential scale. However, even if the residential solar project with FiT seems to be feasible in Bangkok, the power, generated from residential rooftop solar PV, shares a low percentage compared to commercial and industrial-scale. The possible reasons could be from the lack of solar market competition, which lead to the higher solar system costs in the real market, and the lack of effective financing options. In this section, other potential solar policies, apart from FiT, are summarized. If Thai's government is able to apply each policy together with FiT, it should be good to broaden solar PV in residential area of Bangkok.

5.4.1 Additional Financial Incentives along with FiT

Due to the high investment cost of solar PV project, even though Bangkok residents tend to have a good trend of savings as shown in Chapter 4, their actual monthly income is still not large enough to invest on solar projects at the beginning. Some of them might not want to spend their savings on solar since they might prefer to pay for other important issues, such as their children's education and health insurance, and also they might not feel comfortable with this risk since it will take more than 4 years (with incentives) and 10 years (without incentives) to recover all costs. Therefore, it would be great if Thai's government can provide other financial supports, such as lower interest loans, investment grants, and solar leases, to increase solar PV installation rate in Bangkok.

According to Chaianong and Pharino (2015), in Germany, the Federal Ministry for the Environment, Natural Conversation and Nuclear Safety in cooperation with the state owned Kreditanstalt fur Wiederauflau (KfW) bank offered programs that provide loans at lower interest rate to help increase solar PV installation. In 1999, Germany started 100,000 solar roof programs by giving zero percent of interest rate for a loan before increasing the interest rate to 1.9 percent per year in 2000.

An investment grant is another option of financial incentive. Based on Malley *et al.* (2012), in 2014 the state of Maryland gave the Clean Energy Grant incentives based on several factors, including available funds, economic scale, and total offered grants. As for solar PV, the flat award is 1,000 US$ per project. With this incentive, the homeowners can reduce their investment cost and be able to install solar PV more than usual.

A solar lease is a legal contract in which a residential owner leases solar PV panels and other installed equipment from a provider. The advantage of this lease is the owner does not have to pay for all investment costs, they need to pay only monthly fee for equipment's leasing. However, the residential home owner does not actually own the PV on their roof. Normally, the leasing period is around 15-25 years based on solar project's period in each residential area. Moreover, it is a fixed rate that the residents do not need to be worried about an inflation rate that might change the monthly payment. This policy might be preferable to the homeowners who do not want to spend a large amount of money on investing solar PV project. However, the solar lease is not generally available in all areas, but in the U.S. it is available in states such as California, Arizona, and Texas (Residential Solar 101, undated).

5.4.2 Net Metering

Net metering is another policy that could help incentivize PV installations in Bangkok residents. During net metering customers are only billed for their net energy use from the grid. It is an electricity policy that the meter can work in both forward and reverse direction. If the residential solar PV panels are able to generate electricity more than the demand of the owner, this electricity is added to the grid; the meter runs backwards, and the PV owner is effectively compensated at the same price of grid electricity. When electricity demand is more than electricity produced from solar, the electricity flows from the grid to each home and the meter runs forward.

The advantages of net metering policy include:

- Financial credit is provided for the excess power;

- Seasonal profits- Solar energy produced in summer can help reduce costs of electricity in winter.

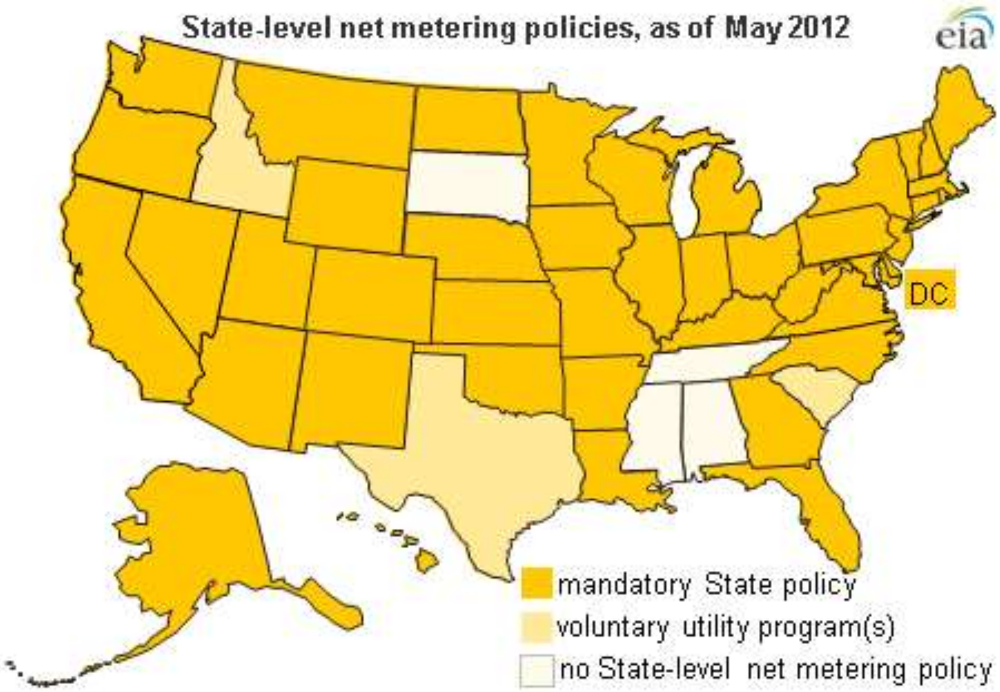

Figure 5.23: Net Metering Policy in the U.S.

(U.S. Energy Information Administration, 2012)

In the U.S., 43 states, Washington D.C., and 4 territories have adopted a net metering policy as shown in Fig. 5.23. Most of them mandate net metering as State policy, while some of them, such as Texas, are run based on voluntary utility program(s). Due to the successful experiences from countries using net metering policy, it is likely a very useful policy to adopt in Bangkok.

5.4.3 Renewable Portfolio Standard (RPS)

A renewable portfolio standard (RPS) is another policy that can help drive solar implementation in Bangkok. It is a regulatory mandate to generate renewable energy production. The RPS requirement leads to a responsibility of electricity supply companies to generate electricity from renewable energy resources and meet a specified mandatory fraction. The power plants that produce electricity from renewable energy, normally, earn a certificate for every 1 MWh of power generated (Renewable Energy Certificate: REC), which is similar to Tradable Green Certificates (TGC) in the European countries. Also, the renewable plant owners can sell these credits to other power plant companies that do not generate their share of renewable energy per the RPS (Burns and Kang, 2012).

The U.S. is one of example countries that used RPS to increase renewable energy generation. As seen in Fig. 5.24, 29 states now have the RPS. Iowa was the first state that adopted this policy. The requirement of RPS is different among the States. To illustrate this point, Texas has established the RPS in 1999 with the requirement of 5,880 MW of renewable energy capacity by 2015, while California started this policy in 2002 by mandating 33 percent of total electricity production from renewable energy by 2020 (National Conference of State, 2014).

Figure 5.24: Renewable Portfolio Standard (RPS) Policy in the U.S.

(National Conference of State, 2014)

Solar Renewable Energy Credit (SREC) is an example form of REC, which is created for every 1 MWh of solar energy produced. It is also traded between nine states in the U.S. - District of Columbia (DC), Delaware (DE), Massachusetts (MA), Maryland (MD), North Carolina (NC), New Hampshire (NH), New Jersey (NJ), Ohio (OH), and Pennsylvania (PA). If one of these states fails to meet the solar requirement, they need to pay the Solar Alternative Compliance Payment (SACP), which is different among the nine states. Thus, there are three ways to acquire SREC- increasing solar production, buy SREC from private company, or pay the SACP. Normally, a SREC has a limited lifetime, which is between 2-5 years (Burns and Kang, 2012). Table 5.4 summarizes the details of SREC policy in the U.S.

State	**Initiated Year**	**Target**	**SREC life (Years)**	**2010 SACP (US$)**
DC	2007	2.5% by 2023	3	500
DE	2008	3.5% by 2026	3	400
MA	2010	400 MWp by 2020	1	600
MD	2008	2% by 2023	3	400
NC	2010	0.2% by 2018	2	-
NH	2010	0.3% by 2014	2	160.01
NJ	2004	5,326 GWh by 2026	3	693.10
OH	2009	0.5% by 2024	5	400
PA	2009	0.5% by 2021	3	654.37

Table 5.4: Overview of SERC in 9 states (Adapted from Burns and Kang, 2012).

Owing to the successful experiences from the U.S. and the European countries, an effective RPS should be able to be help develop solar PV in Thailand. Currently, in Thailand, there is only a renewable energy goal, but it is not a requirement such as with an RPS. If these policies are implemented in Thailand, solar PV installation rate would be increased.

5.4.4 Tax Credit

A tax credit is one of the effective policies for promoting renewable energy that used in many countries, including the U.S. Tax credit can be classified into two groups, which are investment tax credit (ITC) and production tax credit (PTC). Focusing on solar energy in the U.S. as an example, according to Solar Energy Industries Association (2015), the solar investment tax credit (ITC) is a 30 percent tax credit for residential solar users. This policy will expire in 2016. The homeowners can apply this tax credit to decrease their income taxes. Therefore, tax credit seems to be appropriate with high income tax payers, who might be interested in reducing their tax payments.

This tax policy created a significant change for solar installation growth in the U.S. Also, during this time the costs of solar have dropped continuously. Thus, since the ITC started in 2006, PV installation has experienced a compound annual growth rate of 76 percent. Also, the jobs related to solar energy industries have grown by 86 percent in the last four years (Solar Energy Industries Association, 2015).

The tax credit could be another effective policy that can be adopted in Thailand. Due to the fact that it is related to tax incomes, it might not be able to encourage low tax income payers, who normally pay taxes around 10 percent of their yearly incomes. However, some residents in Bangkok are high tax income payers (they usually pay taxes more than 35 percent of their yearly incomes); so, this policy should be suitable with them because they might be interested in reducing their tax payments.

It can be concluded that different policies might be suitable for different groups of people. For instance, tax credits seem to be appropriate with high income tax payers, who might be interested in reducing their tax payments, while low income tax payers might be interested in FiT or low interest rate loans since they need these incentives to reduce capital costs for solar PV investment. Net metering is another policy that can be used in every scale, whereas, as for the energy credit, it might be preferable to industrial scale to earn and trade a credit along with their products.

5.5 Policy Barriers

According to the survey conducted by the Energy Research Institute in Thailand on August 28, 2014 (Tongsopit, 2015), solar PV development barriers can be categorized into five groups: are policy framework, governance, cost, technical, and environmental. In the survey, each category was ranked as a barriers index as shown in Fig. 5.25. Among five categories, policy framework seems to have the highest barrier index followed by governance, cost, technical and environmental.

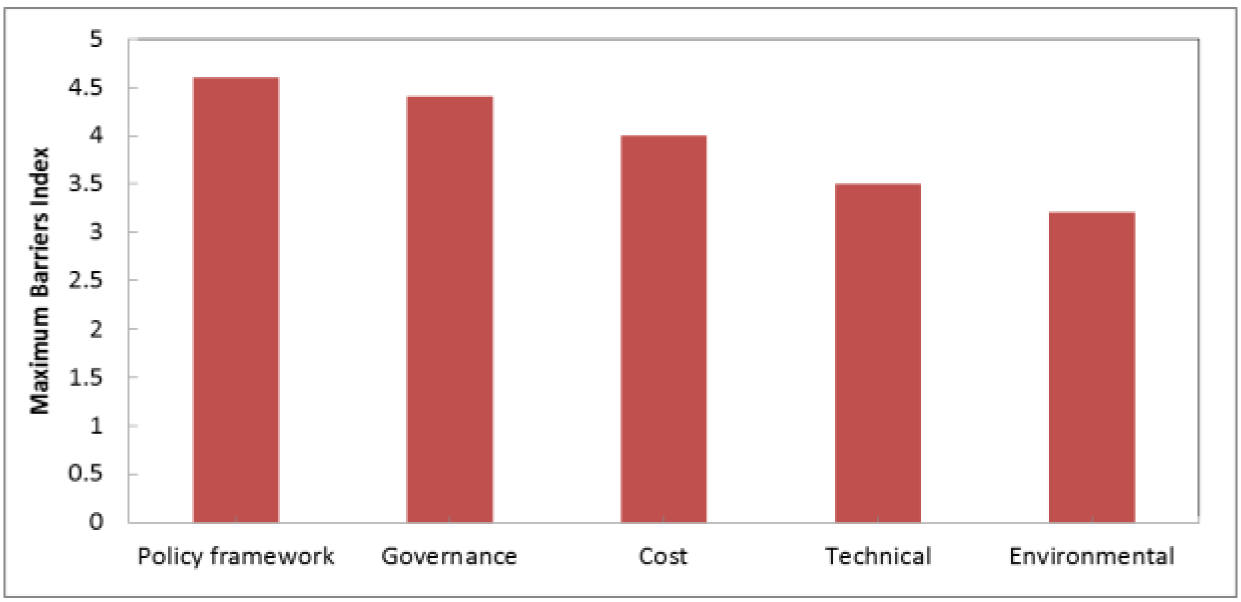

Figure 5.25: Maximum Barrier Index of Thailand Solar PV's Development (Adapted from Tongsopit, 2015).

Barriers by Category	The Highest Barrier Index
Policy Framework	Inconsistent support due to political reasons
Cost	High initial cost of solar modules
Governance	Complicated regulations and permitting procedure
Technical	Lacking installations, operation and safety standards
Environmental	Using a lot of land replacing farming areas

Table 5.5: The Highest Barrier Index by Category (Adapted from Tongsopit, 2015).

Table 5.5 shows the highest index barrier by category of Thailand's solar PV development. As indicated in technical and economic chapter, Thailand lacks skilled manpower with the technical experience for solar installation and operation. Further, solar investment costs can still be cost-prohibitive in case of no incentives and policies even though the LCOE of solar is very near that of grid electricity. Apart from these two, the governance barriers seem to impede solar implementation because of the permitting procedure that takes time. In Thailand, the processes for applying for the FiT are very time-consuming. Sometimes residents must deal with the inconsistent support (e.g., of incentives) due to changes in political leadership, and this might slow down permitting processes for obtaining solar incentives. Environmental barriers are other factors that delay the solar projects since some environmentalists are concerned about solar farms replacing farm land; however, this land replacement should not be an issue for solar rooftop in metropolitan areas.

The cash flow analysis clearly shows that the FiT makes solar projects feasible in Bangkok for both residential scale and large scale. However, there are some policy barriers that obstruct solar implementation. In Fig. 5.26, most of barriers indicate that there are some problems with the visions of successive Thai governments and the inconsistent support due to changing politics. There is a need for monitoring systems that track solar users and the policies that influenced PV adoption. These data determine which policies are suitable to improve solar PV policy in Thailand. Different groups of residents benefit from different solar policies, thus, it should be helpful to have a monitoring system to evaluate the effectiveness of the policies.

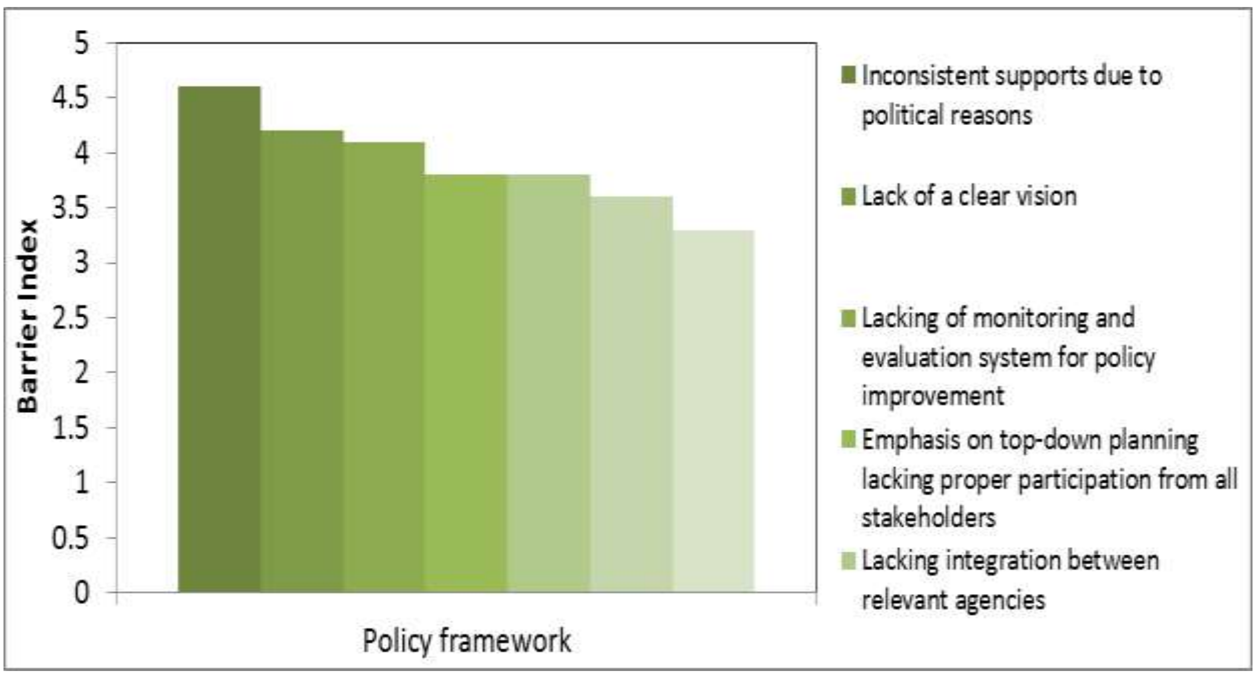

Figure 5.26: Policy Framework Barrier Index

(Adapted from Tongsopit, 2015)

5.6 Policy Analysis Summary

	NPV (US$/kWh)	IRR (%)	PBP (Years)	LCOE (US$/kWh)
Residential scale (Without incentives)	-0.006	6.0	14.2	0.14
Residential scale (With incentives)	0.01	8.7	10.7	0.14
Large scale (Without incentives)	0.013	9.4	11.2	0.13
Large scale (With incentives)	0.0017	9.5	11.0	0.13

Table 5.6: Financial Analysis Summary of Solar PV Project in Bangkok.

Due to the past higher costs of solar PV, the Thai government started with a solar incentive, the Adder, by paying utility-scale PV owners a subsidy of 0.19 US$/kWh in 2010 on top of the wholesale electricity price. Thus, the adder was a direct government transfer to utility scale PV owners. In 2013, the incentive was changed to the Feed-in Tariff (FiT) scheme, which is a fixed amount per kWh paid during the project lifetime.

With the FiT, the NPV increases from -0.006 to 0.01 US$/kWh and the IRR rises from 6 to 8.7percent, while PBP decreases from 14.2 to 10.7 years. Compared to large scale, with the FiT, the NPV increases from 0.013 to 0.017 US$/kWh and the IRR rises from 9.4 to 9.5 percent, while PBP decreases from 11.2 to 11 years. It is noticeable that NPV, IRR and PBP of large-scale in both cases are slightly different because the patterns of large-scale load and distributed solar electricity are aligned; therefore, there is not much excess electricity to sell back to the grid in order to receive FiT, unlike residential scale. These financial analyses describe whether solar projects with incentives seem to be feasible in Bangkok under the parameter assumptions (in Table 5.1) and it is also possible to reduce the amount of current FiT of both scales in the future due to the continuously increasing price of grid electricity . Although LCOE for residential PV is higher than for large scale (e.g., commercial and industrial), Thailand's FiT makes PV attractive to both types of customers.

Apart from the FiT, it is necessary to use other financial incentives, such as tax credit, along with FiT to increase solar PV installation rates in Bangkok. Different policies might be suitable with different group of people. For instance, a tax credit seems to be appropriate for high income tax payers (citizens or companies), who might be interested in reducing their tax payments, while low income tax payers might be interested in FiT or low interest rate loans since they needs these incentives to reduce capital costs for solar PV investment. Moreover, net metering is another effective policy that can be used in every scale, while, as for the energy credit, it might be preferable to industrial scale, who want to earn and trade a credit along with their products.

Policy and governance barriers are other two barriers that obstruct solar PV installation in Bangkok because of the complicated regulations and permitting procedure. In Thailand, to apply for receiving FiT, the processes are complicated and time-consuming. The residents also have to deal with the inconsistent supports due to the political reasons that might slow down permitting process of getting solar incentives. Further research should consider these barriers and determine how to simplify the permitting processes. Furthermore, in order to improve solar policy, the government could collect data to track solar users with offered policies to determine whether the policies are suitable for their cases or not.

Chapter 6: Discussion: The Possibility of Solar PV Installation in Bangkok

This chapter describes the discussion of the possibility of solar PV installation in Bangkok by comparing residential scale to large scale considering technical, economic, and policy analysis (in Chapter 3-5), together with the general information of Bangkok, such as urbanization rate (Section 6.1) and area use (Section 6.2), to determine whether residential scale of solar PV is appropriate for implementing in Bangkok or not (Section 6.3).

6.1 Urbanization Rate

In the past, Thailand had one of the lowest urbanization rates in Asia. However, recently, according to the United Nations (2011) and Water Development and Research Group (undated), at the mid-year of 2014, the rural population was 34.2 million, while the urban population was 33 million. The urban percentage was around 49.2 percent. Due to continued increasing population in urban area (See Fig. 6.1), Thailand is expected to reach the urbanization level of 70 percent by 2050. Bangkok is the largest urban area in Thailand. Thus, it is a good place to install decentralized solar PV.

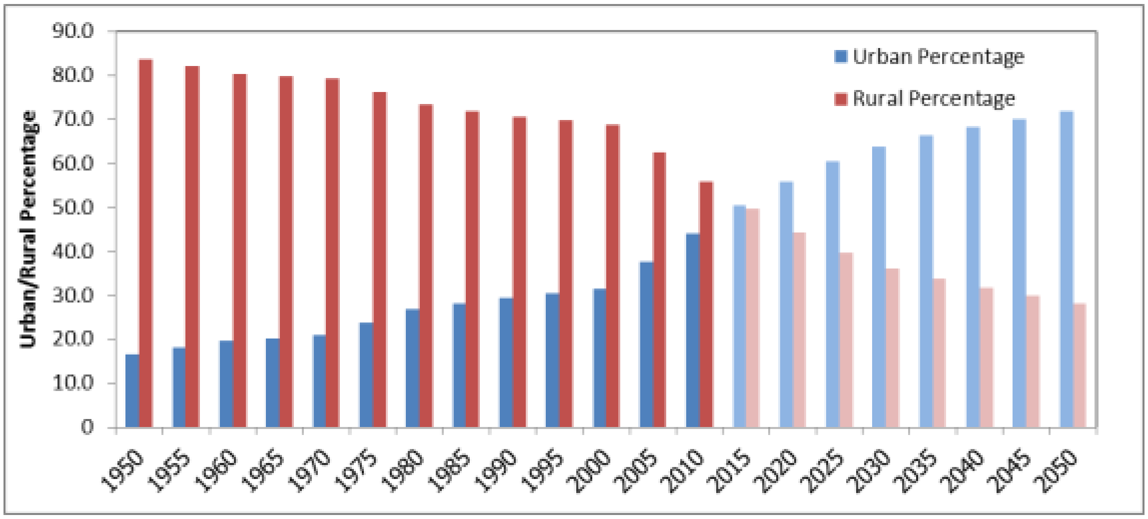

Figure 6.1: Data during 1950-2014 and Projections during 2015-2050 of Urban and Rural Percentage in Thailand (The total population at mid-year of 2014 was 67.2 million.) (The United Nations, 2011)

6.2 Land Use

Based on Bangkok Metropolitan Administration (2012), the total area of Bangkok is 1,568.7 km^2. The existing land use area in Bangkok can be categorized into residential, agricultural, commercial, manufacturing, undeveloped land, and others (Fig. 6.2). More than 75 percent of all area in Bangkok has been used for residential, agricultural, commercial and other purposes, while approximately one-fourth of area is an undeveloped area. Furthermore, it is noticeable that in Bangkok, the manufacturing area is only around 5.4 km^2, which around 1 percent of total area due to the fact that Thai government has planned to spread the manufacturing to other regions outside Bangkok. On the other hand, focusing on the residential areas, they have been grown very quickly the last 10 years (around 60,000 household per year, or 5.29 percent per year). Consequently, Bangkok tends to be an urbanized area much more than in the past.

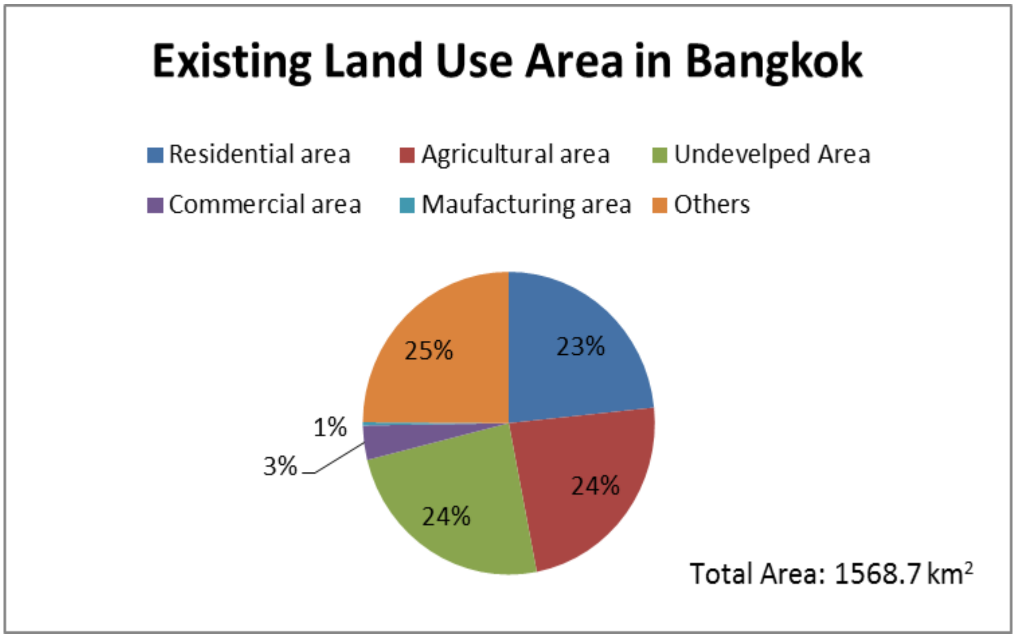

Figure 6.2: Existing Land Use in Bangkok

(Bangkok Metropolitan Administration, 2012)

6.3 The Possibility of Distributed Solar PV in Bangkok

According to technical, economic, and policy analysis in chapter 3-5, both residential-scale and large-scale solar PV is feasible and able to reach grid parity easily if Thai government continues offering the financial incentives. Unlike large scale electricity load pattern, the residential-scale load pattern peaks in the late evening and thus is not in alignment with solar radiation. However, during midday, energy generated from solar is able to exceed load demand of residential scale, so it is useful to store or sell energy back to the grid in order to increase the energy security in Thailand and possibly defer transmission and possibly some distribution investments.

	Residential Scale	**Large Scale (Manufacturing)**
Goal (MW)	3,000	3,000
Unit		
Capacity (kW each)	1-10	250-1,000
Number of Units needed	300,000-3,000,000	3,000-12,000
Current Units in Bangkok	2,593,827 [1]	18,927 [2]
Area		
Efficiency Performance (W/m^2)	175 [3]	175 [3]
Area Required for 3,000 MW Solar PV (km^2)	17	17
Actual Area in Bangkok (km^2)	366 [4]	6 [4]

Table 6.1: Comparison between Residential Scale and Large Scale of Solar PV Implementation in Bangkok

[1] Bureau of Registration Administration, 2013

[2] Department of City Planning, 2008

[3] International Energy Agency, 2010 (for crystalline solar panels)

[4] Bangkok Metropolitan Administration, 2012

As mentioned earlier, around 25 percent of all areas in Bangkok have been used for residential purposes, while only 1 percent of area is for manufacturing- an example of large scale user. Table 6.1 shows the comparison between the opportunities of solar implementation of both scales in Bangkok. Focusing on units required for installing 3,000 MW solar PV, as for residential scale, since the capacity per unit is around 1-10 kW, the number of households needed is between 300,000 to 3,000,000. When compared to the current residential units in Bangkok, which are around 2.5 million, there are enough residential units to install 3,000 MW of solar PV in residential areas of Bangkok. Looking deeply into the areas for implementing 3,000 MW of solar PV, calculated based on peak solar insolation to electricity conversion of 175 W/m^2 the required area is approximately 17 km^2, which is much less than the actual area of residential area in Bangkok (366 km^2). Therefore, after considering both a number of households and required areas for an installation, it can be concluded that 3,000 MW of solar PV could be installed in the residential areas of Bangkok. Future research is needed to determine how much of the residential areas are feasible (e.g., no shading problems, applicable roof space, etc.).

Per large scale (manufacturing), the capacity per unit is between 250-1,000 kW. In order to install 3,000 MW of solar PV, a number of large-scale units required is around 3,000-12,000 units, which is less than the current manufacturing units in Bangkok. On the other hand, when considering manufacturing areas in Bangkok, it has only 6 km^2, which is not as much of the total required areas for installing 3,000 MW of solar PV. However, it is not to say that large-scale of solar PV is not feasible in Bangkok, but it might need to install in other areas, such as residential and commercial areas, together with manufacturing areas in order to meet 3,000 MW of solar PV's goal.

	Residential Scale
Goal (MW)	3,000
Current household units in Bangkok	2,593,827
Suggested capacity per household (kW each)	***1.16***
Actual roof area needed per household (m^2)	***6.6*** [5]

Table 6.2: Summary of suggested capacity per household and area needed for residential-scale solar PV installation in Bangkok.

[5] Calculated based on efficiency performance from Table 6.1.

Focusing on residential scale, table 6.2 summarizes the suggested capacity and actual roof area needed per household of solar PV. The capacity per household should be greater than 1.16 kW , while the estimated roof area required per household is around 6.6 m^2, which is much less than average house area in Bangkok (75 m^2) (Bangkok Metropolitan Administration, 2012 and National Statistical Office, 2012). Moreover, it is necessary to consider the some other installation problems of distributed solar energy, since there will be much required in terms of distribution system costs (e.g., power lines, meters, transformers, etc.). One must also focus on the policies and regulations to enable PV installation and concepts such as net metering (see technical barriers in Chapter 3).

Apart from the installation problems, the data from Geographic Information System (GIS) and satellite data is needed to confirm exactly where and how much roof area is applicable for 3,000 MW of solar PV. This remains a topic for future research.

Chapter 7: Conclusion and Future Work

7.1 Conclusion

Due to the dependence on conventional energy resources and the increasing of electricity demand, Thailand has been facing the energy problem due to the high dependence on imported non-renewable energy that needs to be solved. Using alternative energy, like solar energy, should be one of the effective solutions to help lessen the required loads from conventional power plants. This study presents an analysis for promoting distributed residential solar PV in Bangkok in terms of technical, economic, and policy analysis. Furthermore, in order to better understand this analysis, the feasibility of large-scale solar PV is investigated to make a comparison with the residential scale.

In Bangkok, the perfect period of time for generating electricity from solar PV is from 9am-3pm, especially in summer, while the peak residential load is at night (9pm till midnight). It means that residential load and distributed generation patterns (assuming south-facing panels) of the average day are not aligned. However, even if the solar PV panels might not totally decrease peak load of electricity uses in Bangkok, they are still useful in terms of lowering electric demands in each day, especially at noon. The total residential electricity demand from the grid in one day basis can decrease by 38 percent after installing 3,000 MW of solar PV. Additionally, the residential distributed electricity from solar PV at its peak power output (approximately noon) is 130 percent of residential load at that time. This means power generated from solar panels can exceed residential electric demands during the midday. So, it should be good to store, or sell distributed energy back to the grid (e.g., to large-scale users in Bangkok or to consumers outside of Bangkok) in order to reduce electricity generation from fossil fuels. On the other hand, a typical daily (an average day) pattern of power output from 3,000 MW installed solar PV and large-scale electric loads in Bangkok are well-matched. Thus, solar PV installation is able to reduce grid electricity consumption (e.g., in MWh) of large scale by 16.7 percent. Considering the midday, the peak power output from distributed solar PV is 77 percent of large-scale load at that time. Apart from the relationship between distributed energy and electricity load, technical barrier is another issue that affect the implementation rate of solar PV since currently, in Thailand, both technology and manpower of solar PV are still developing.

According to economic analysis, solar PV has a higher installed cost, but lower operating cost compared to fossil fuel-based, like coal and natural gas. Focusing on LCOE of solar PV in Thailand for both residential scale (0.14 US$ per kWh) and large scale (0.13 US$ per kWh), it is higher than grid price (0.12 US$ per kWh). To be more economically viable, the project's LCOE must be equal to or less than the average retail electricity rate, but it is already very close. Some incentives and policies are needed to further decrease costs of solar energy in Thailand. In addition, the economics of consumer's study in Bangkok indicates that only 2 percent of household income, out of 28 percent saved, is needed to fund residential solar PV in Bangkok, whereas, for large scale, only 1 out of 22 percent saved and 4 out of 50 percent saved of income, is needed to fund solar PV for manufacturing and hotel, respectively. Based on savings behavior of residents in Bangkok, they should have enough money for investing on solar PV project. However, due to the higher cost of solar PV than grid price, they might not be interested installing solar PV even if residents in Bangkok tend to save their money every month. Consequently, Thai government should promote the incentives and/or policy to drive solar PV in Bangkok.

Presently, the feed-in tariff (FiT) scheme has been implemented in Thailand to help promote solar PV installation since 2013.With the current FiT, the NPV, IRR, and PBP of residential scale is 0.01 US$/kWh, 8.7percent and 10.9 years, respectively, while they are 0.02 US$/kWh, 11 percent and 9.5 years for large scale. Both projects seem to be feasible in Thailand. In order to keep projects viable, it might also be possible to decrease FiT level in the future due to the continuously increasing of grid electricity. Moreover, it is essential to consider any other policies due to the fact that different policies might be suitable with different group of people. A tax credit seems to be appropriate for high income tax payers, who might be interested in reducing their tax payments, whereas low income tax payers might be interested in FiT or low interest rate loans since they need these incentives to reduce capital costs for solar PV investment. Energy credits and RPS might match with industrial PV installations who could use these credits for promoting their green products. Nevertheless, in Thailand, there are some governance barriers that slow the processes of getting solar incentives, so, it is necessary to fasten the permitting process in order to encourage users to starting implementing solar PV for their households.

Bangkok has a high opportunity for implementing residential solar PV due to the growing of urbanized areas. As for land use of Bangkok, almost one-fourth of total areas are used for residential purposes, while only less than 1 percent is for industrial uses. Based on the current number of household and large-scale units, residential-scale solar PV is only the option for installing 3,000 MW solar PV in the city. The suggested capacity per household of residential solar PV is more than 1.16 kW and the actual roof area needed per household is around 6.6 m^2 in order to achieve the renewable energy goal of 3,000 MW.

7.2 Future Work

The recommendations for future work are described below:

1. The study of relationship between distributed energy and electric load should be extended to monthly or seasonal basis in order to understand the opportunity of solar PV installation in the whole year, not only an average day.
2. In order to better comprehend the consumer behaviors, the survey might be conducted to know what the main reasons that residents in Thailand are not interested in implementing solar PV in their households are.
3. In the suggested policies section (tax credits, RPS, etc.), it should be extended to consider the LCOE, NPV, IRR, and PBP of solar project after applying each policy in order to make a comparison more effectively. Furthermore, the feasibility of project with policy mix could be considered to help evaluate the appropriate solar policies in Bangkok. As part of this work, it would be good to calculate the levelized avoided cost of electricity (LACE) that values the solar PV electricity output based upon the time of the day the electricity is generated and compares it to the cost of grid electricity as it also varies with demand changes throughout the day.
4. Geographic Information System (GIS) data might be needed to confirm if the numbers of applicable roof areas in Bangkok are enough to practically install 3000 MW of PV. This current study provides only a first rough estimation from the current land used data reported from governmental institution in Thailand, without accurate satellite data that can indicate important roof characteristics such as shading, orientation, and size.

Appendix

Residential Cash Flow (Without incentives)																										
Operating Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Production																										
Annual energy (AC kWh)	0	4,443,020,000	4,420,810,000	4,398,700,000	4,376,710,000	4,354,830,000	4,333,050,000	4,311,390,000	4,289,830,000	4,268,380,000	4,247,040,000	4,225,810,000	4,204,680,000	4,183,650,000	4,162,730,000	4,141,920,000	4,121,210,000	4,100,600,000	4,080,100,000	4,059,700,000	4,039,400,000	4,019,210,000	3,999,110,000	3,979,110,000	3,959,220,000	3,939,420,000
Savings																										
Value of electricity savings ($)	0	387,387,328	408,140,000	429,624,704	451,859,904	474,737,312	498,143,648	521,880,160	545,823,872	569,914,240	594,114,496	618,195,328	641,671,936	664,787,264	687,821,376	710,626,432	733,070,592	754,881,408	776,004,800	796,564,928	816,855,872	836,922,176	856,790,656	876,599,360	896,669,696	917,167,360
Operating Expenses																										
Variable cost in $/MWh		44,430,200	46,772,170	49,237,464	51,832,812	54,564,964	57,441,006	60,468,795	63,656,060	67,011,358	70,543,558	74,262,000	78,176,333	82,296,877	86,634,709	91,201,305	96,008,517	101,069,028	106,396,455	112,004,626	117,908,346	124,123,511	130,665,932	137,553,180	144,803,811	152,436,269
Insurance		31,020,000	31,888,560	32,781,440	33,699,320	34,642,901	35,612,902	36,610,063	37,635,145	38,688,929	39,772,219	40,885,841	42,030,645	43,207,503	44,417,313	45,660,998	46,939,506	48,253,812	49,604,919	50,993,856	52,421,684	53,889,492	55,398,397	56,949,553	58,544,140	60,183,376
Property tax		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salvage value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses		75,450,200	78,660,730	82,018,904	85,532,132	89,207,865	93,053,908	97,078,859	101,291,205	105,700,287	110,315,777	115,147,842	120,206,978	125,504,380	131,052,023	136,862,303	142,948,023	149,322,840	156,001,374	162,998,482	170,330,031	178,013,003	186,064,330	194,502,732	203,347,951	212,619,645
Project Debt																										
Total installed cost	6,204,000,000																									
Debt amount	3,102,000,000																									
Equity	3,102,000,000																									
Debt payments																										
Balance		3,102,000,000	2,790,269,865	2,459,368,327	2,108,116,344	1,735,262,365	1,339,477,865	919,352,619	473,389,670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest		190,773,000	171,601,597	151,251,152	129,649,155	106,718,635	82,377,889	56,540,186	29,113,465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Principal		311,730,135	330,901,538	351,251,983	372,853,980	395,784,499	420,125,246	445,962,949	473,389,670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total P&I Payment		502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-tax cash flow	-3,102,000,000	-577,953,335	-581,163,865	-584,522,039	-588,035,267	-591,711,000	-595,557,043	-599,581,994	-603,794,340	-105,700,287	-110,315,777	-115,147,842	-120,206,978	-125,504,380	-131,052,023	-136,862,303	-142,948,023	-149,322,840	-156,001,374	-162,998,482	-170,330,031	-178,013,003	-186,064,330	-194,502,732	-203,347,951	-212,619,645
After-tax annual costs	-3,102,000,000	-577,953,335	-581,163,865	-584,522,039	-588,035,267	-591,711,000	-595,557,043	-599,581,994	-603,794,340	-105,700,287	-110,315,777	-115,147,842	-120,206,978	-125,504,380	-131,052,023	-136,862,303	-142,948,023	-149,322,840	-156,001,374	-162,998,482	-170,330,031	-178,013,003	-186,064,330	-194,502,732	-203,347,951	-212,619,645
After-tax value of energy generated by system	0	387,387,328	408,140,000	429,624,704	451,859,904	474,737,312	498,143,648	521,880,160	545,823,872	569,914,240	594,114,496	618,195,328	641,671,936	664,787,264	687,821,376	710,626,432	733,070,592	754,881,408	776,004,800	796,564,928	816,855,872	836,922,176	856,790,656	876,599,360	896,669,696	917,167,360
After-tax cash flow	-3,102,000,000	-190,566,007	-173,023,865	-154,897,335	-136,175,363	-116,973,688	-97,413,395	-77,701,834	-57,970,468	464,213,953	483,798,719	503,047,486	521,464,958	539,282,884	556,769,353	573,764,129	590,122,569	605,558,568	620,003,426	633,566,446	646,525,841	658,909,173	670,726,326	682,096,628	693,321,745	704,547,715
Cumulative After-tax Cash Flow	-3,102,000,000	-3,292,566,007	-3,465,589,872	-3,620,487,206	-3,756,662,570	-3,873,636,258	-3,971,049,653	-4,048,751,487	-4,106,721,955	-3,642,508,002	-3,158,709,284	-2,655,661,797	-2,134,196,839	-1,594,913,956	-1,038,144,602	-464,380,473	125,742,096	731,300,664	1,351,304,090	1,984,870,535	2,631,396,377	3,290,305,550	3,961,031,876	4,643,128,504	5,336,450,249	6,040,997,964
Payback Period Calculation																										
Initial investment	6,204,000,000																									
After-tax cash flow		-190,566,007	-173,023,865	-154,897,335	-136,175,363	-116,973,688	-97,413,395	-77,701,834	-57,970,468	464,213,953	483,798,719	503,047,486	521,464,958	539,282,884	556,769,353	573,764,129	590,122,569	605,558,568	620,003,426	633,566,446	646,525,841	658,909,173	670,726,326	682,096,628	693,321,745	704,547,715
Debt interest payment		190,773,000	171,601,597	151,251,152	129,649,155	106,718,635	82,377,889	56,540,186	29,113,465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment		311,730,135	330,901,538	351,251,983	372,853,980	395,784,499	420,125,246	445,962,949	473,389,670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow for payback calculation	-6,204,000,000	311,937,128	329,479,270	347,605,800	366,327,772	385,529,447	405,089,740	424,801,301	444,532,667	464,213,953	483,798,719	503,047,486	521,464,958	539,282,884	556,769,353	573,764,129	590,122,569	605,558,568	620,003,426	633,566,446	646,525,841	658,909,173	670,726,326	682,096,628	693,321,745	704,547,715
Cumulative cash flow	-6,204,000,000	-5,892,062,872	-5,562,583,602	-5,214,977,802	-4,848,650,030	-4,463,120,584	-4,058,030,844	-3,633,229,543	-3,188,696,876	-2,724,482,923	-2,240,684,205	-1,737,636,718	-1,216,171,760	-676,888,877	-120,119,523	453,644,606	1,043,767,175	1,649,325,743	2,269,329,169	2,902,895,614	3,549,421,456	4,208,330,629	4,879,056,955	5,561,153,583	6,254,475,328	6,959,023,043

Table A: Cash Flow of Residential Solar PV Project (Without Incentives)

Residential Cash Flow (With incentives)													
Operating Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Production													
Annual energy (AC kWh)	0	4,443,020,000	4,420,810,000	4,398,700,000	4,376,710,000	4,354,830,000	4,333,050,000	4,311,390,000	4,289,830,000	4,268,380,000	4,247,040,000	4,225,810,000	4,204,680,000
Savings													
Value of electricity savings ($)	0	630,346,496	636,825,280	643,279,872	649,707,200	656,198,720	662,827,072	669,746,304	677,047,168	684,785,920	692,989,760	701,833,216	711,647,488
Operating Expenses													
Variable cost in $/MWh		44,430,200	46,772,170	49,237,464	51,832,812	54,564,964	57,441,006	60,468,795	63,656,060	67,011,358	70,543,558	74,262,000	78,176,333
Insurance		31,020,000	31,888,560	32,781,440	33,699,320	34,642,901	35,612,902	36,610,063	37,635,145	38,688,929	39,772,219	40,885,841	42,030,645
Property tax		0	0	0	0	0	0	0	0	0	0	0	0
Salvage value		0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses		75,450,200	78,660,730	82,018,904	85,532,132	89,207,865	93,053,908	97,078,859	101,291,205	105,700,287	110,315,777	115,147,842	120,206,978
Project Debt													
Total installed cost	6,204,000,000												
Debt amount	3,102,000,000												
Equity	3,102,000,000												
Debt payments													
Balance		3,102,000,000	2,790,269,865	2,459,368,327	2,108,116,344	1,735,262,365	1,339,477,865	919,352,619	473,389,670	0	0	0	0
Interest		190,773,000	171,601,597	151,251,152	129,649,155	106,718,635	82,377,889	56,540,186	29,113,465	0	0	0	0
Principal		311,730,135	330,901,538	351,251,983	372,853,980	395,784,499	420,125,246	445,962,949	473,389,670	0	0	0	0
Total P&I Payment		502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	502,503,135	0	0	0	0
Pre-tax cash flow	-3,102,000,000	-577,953,335	-581,163,865	-584,522,039	-588,035,267	-591,711,000	-595,557,043	-599,581,994	-603,794,340	-105,700,287	-110,315,777	-115,147,842	-120,206,978
After-tax annual costs	-3,102,000,000	-577,953,335	-581,163,865	-584,522,039	-588,035,267	-591,711,000	-595,557,043	-599,581,994	-603,794,340	-105,700,287	-110,315,777	-115,147,842	-120,206,978
After-tax value of energy generated by system	0	630,346,496	636,825,280	643,279,872	649,707,200	656,198,720	662,827,072	669,746,304	677,047,168	684,785,920	692,989,760	701,833,216	711,647,488
After-tax cash flow	-3,102,000,000	52,393,161	55,661,415	58,757,833	61,671,933	64,487,720	67,270,029	70,164,310	73,252,828	579,085,633	582,673,983	586,685,374	591,440,510
Cumulative After-tax Cash Flow	-3,102,000,000	-3,049,606,839	-2,993,945,424	-2,935,187,590	-2,873,515,658	-2,809,027,938	-2,741,757,909	-2,671,593,599	-2,598,340,771	-2,019,255,138	-1,436,581,156	-849,895,781	-258,455,271
Payback Period Calculation													
Initial investment	6,204,000,000												
After-tax cash flow		52,393,161	55,661,415	58,757,833	61,671,933	64,487,720	67,270,029	70,164,310	73,252,828	579,085,633	582,673,983	586,685,374	591,440,510
Debt interest payment		190,773,000	171,601,597	151,251,152	129,649,155	106,718,635	82,377,889	56,540,186	29,113,465	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only		0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment		311,730,135	330,901,538	351,251,983	372,853,980	395,784,499	420,125,246	445,962,949	473,389,670	0	0	0	0
Cash flow for payback calculation	-6,204,000,000	554,896,296	558,164,550	561,260,968	564,175,068	566,990,855	569,773,164	572,667,445	575,755,963	579,085,633	582,673,983	586,685,374	591,440,510
Cumulative cash flow	-6,204,000,000	-5,649,103,704	-5,090,939,154	-4,529,678,186	-3,965,503,118	-3,398,512,264	-2,828,739,100	-2,256,071,655	-1,680,315,692	-1,101,230,059	-518,556,077	68,129,298	659,569,808

Residential Cash Flow (With incentives)													
Operating Year	13	14	15	16	17	18	19	20	21	22	23	24	25
Production													
Annual energy (AC kWh)	4,183,650,000	4,162,730,000	4,141,920,000	4,121,210,000	4,100,600,000	4,080,100,000	4,059,700,000	4,039,400,000	4,019,210,000	3,999,110,000	3,979,110,000	3,959,220,000	3,939,420,000
Savings													
Value of electricity savings ($)	722,285,568	733,570,496	745,619,648	758,532,416	772,501,184	787,581,568	803,707,520	820,693,824	838,523,328	857,201,792	876,651,712	896,669,696	917,167,360
Operating Expenses													
Variable cost in $/MWh	82,296,877	86,634,709	91,201,305	96,008,517	101,069,028	106,396,455	112,004,626	117,908,346	124,123,511	130,665,932	137,553,180	144,803,811	152,436,269
Insurance	43,207,503	44,417,313	45,660,998	46,939,506	48,253,812	49,604,919	50,993,856	52,421,684	53,889,492	55,398,397	56,949,553	58,544,140	60,183,376
Property tax	0	0	0	0	0	0	0	0	0	0	0	0	0
Salvage value	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses	125,504,380	131,052,023	136,862,303	142,948,023	149,322,840	156,001,374	162,998,482	170,330,031	178,013,003	186,064,330	194,502,732	203,347,951	212,619,645
Project Debt													
Total installed cost													
Debt amount													
Equity													
Debt payments													
Balance	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest	0	0	0	0	0	0	0	0	0	0	0	0	0
Principal	0	0	0	0	0	0	0	0	0	0	0	0	0
Total P&I Payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-tax cash flow	-125,504,380	-131,052,023	-136,862,303	-142,948,023	-149,322,840	-156,001,374	-162,998,482	-170,330,031	-178,013,003	-186,064,330	-194,502,732	-203,347,951	-212,619,645
After-tax annual costs	-125,504,380	-131,052,023	-136,862,303	-142,948,023	-149,322,840	-156,001,374	-162,998,482	-170,330,031	-178,013,003	-186,064,330	-194,502,732	-203,347,951	-212,619,645
After-tax value of energy generated by system	722,285,568	733,570,496	745,619,648	758,532,416	772,501,184	787,581,568	803,707,520	820,693,824	838,523,328	857,201,792	876,651,712	896,669,696	917,167,360
After-tax cash flow	596,781,188	602,518,473	608,757,345	615,584,393	623,178,344	631,580,194	640,709,038	650,363,793	660,510,325	671,137,462	682,148,980	693,321,745	704,547,715
Cumulative After-tax Cash Flow	338,325,916	940,844,390	1,549,601,735	2,165,186,128	2,788,364,472	3,419,944,666	4,060,653,703	4,711,017,497	5,371,527,822	6,042,665,284	6,724,814,264	7,418,136,009	8,122,683,724
Payback Period Calculation													
Initial investment													
After-tax cash flow	596,781,188	602,518,473	608,757,345	615,584,393	623,178,344	631,580,194	640,709,038	650,363,793	660,510,325	671,137,462	682,148,980	693,321,745	704,547,715
Debt interest payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only	0	0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow for payback calculation	596,781,188	602,518,473	608,757,345	615,584,393	623,178,344	631,580,194	640,709,038	650,363,793	660,510,325	671,137,462	682,148,980	693,321,745	704,547,715
Cumulative cash flow	1,256,350,995	1,858,869,469	2,467,626,814	3,083,211,207	3,706,389,551	4,337,969,745	4,978,678,782	5,629,042,576	6,289,552,901	6,960,690,363	7,642,839,343	8,336,161,088	9,040,708,803

Table B: Cash Flow of Residential Solar PV Project (With FiT = 0.20 US$/kWh)

Large-scale Cash Flow (Without incentives)													
Operating Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Production													
Annual energy (AC kWh)	0	4,443,020,000	4,420,810,000	4,398,700,000	4,376,710,000	4,354,830,000	4,333,050,000	4,311,390,000	4,289,830,000	4,268,380,000	4,247,040,000	4,225,810,000	4,204,680,000
Savings													
Value of electricity savings ($)	0	530,862,944	543,786,816	556,836,224	570,042,880	583,375,616	596,864,192	610,590,016	624,558,208	638,837,504	653,439,424	668,378,304	683,656,832
Operating Expenses													
Variable cost in $/MWh		44,430,200	45,445,927	46,484,758	47,547,437	48,634,411	49,746,127	50,883,385	52,046,543	53,236,316	54,453,322	55,698,194	56,971,442
Insurance		28,380,000	29,174,640	29,991,530	30,831,293	31,694,569	32,582,017	33,494,313	34,432,154	35,396,254	36,387,350	37,406,195	38,453,569
Property tax		0	0	0	0	0	0	0	0	0	0	0	0
Salvage value		0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses		72,810,200	74,620,567	76,476,288	78,378,730	80,328,980	82,328,144	84,377,699	86,478,697	88,632,570	90,840,672	93,104,389	95,425,011
Project Debt													
Total installed cost	5,676,000,000												
Debt amount	2,838,000,000												
Equity	2,838,000,000												
Debt payments													
Balance		2,838,000,000	2,540,799,493	2,228,738,960	1,901,075,401	1,557,028,664	1,195,779,591	816,468,063	418,190,959	0	0	0	0
Interest		141,900,000	127,039,975	111,436,948	95,053,770	77,851,433	59,788,980	40,823,403	20,909,548	0	0	0	0
Principal		297,200,507	312,060,532	327,663,559	344,046,737	361,249,074	379,311,528	398,277,104	418,190,959	0	0	0	0
Total P&I Payment		439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	0	0	0	0
Pre-tax cash flow	-2,838,000,000	-511,910,707	-513,721,074	-515,576,795	-517,479,237	-519,429,487	-521,428,651	-523,478,206	-525,579,204	-88,632,570	-90,840,672	-93,104,389	-95,425,011
After-tax annual costs	-2,838,000,000	-511,910,707	-513,721,074	-515,576,795	-517,479,237	-519,429,487	-521,428,651	-523,478,206	-525,579,204	-88,632,570	-90,840,672	-93,104,389	-95,425,011
After-tax value of energy generated by system	0	530,862,944	543,786,816	556,836,224	570,042,880	583,375,616	596,864,192	610,590,016	624,558,208	638,837,504	653,439,424	668,378,304	683,656,832
After-tax cash flow	-2,838,000,000	18,952,237	30,065,742	41,259,429	52,563,643	63,946,129	75,435,541	87,111,810	98,979,004	550,204,934	562,598,752	575,273,915	588,231,821
Cumulative After-tax Cash Flow	-2,838,000,000	-2,819,047,763	-2,788,982,021	-2,747,722,592	-2,695,158,949	-2,631,212,820	-2,555,777,279	-2,468,665,469	-2,369,686,465	-1,819,481,531	-1,256,882,779	-681,608,865	-93,377,043
Payback Period Calculation													
Initial investment	5,676,000,000												
After-tax cash flow		18,952,237	30,065,742	41,259,429	52,563,643	63,946,129	75,435,541	87,111,810	98,979,004	550,204,934	562,598,752	575,273,915	588,231,821
Debt interest payment		141,900,000	127,039,975	111,436,948	95,053,770	77,851,433	59,788,980	40,823,403	20,909,548	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only		0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment		297,200,507	312,060,532	327,663,559	344,046,737	361,249,074	379,311,528	398,277,104	418,190,959	0	0	0	0
Cash flow for payback calculation	-5,676,000,000	458,052,744	469,166,249	480,359,936	491,664,150	503,046,636	514,536,048	526,212,317	538,079,511	550,204,934	562,598,752	575,273,915	588,231,821
Cumulative cash flow	-5,676,000,000	-5,217,947,256	-4,748,781,007	-4,268,421,071	-3,776,756,921	-3,273,710,285	-2,759,174,237	-2,232,961,920	-1,694,882,408	-1,144,677,475	-582,078,723	-6,804,808	581,427,013

Large-scale Cash Flow (Without incentives)													
Operating Year	13	14	15	16	17	18	19	20	21	22	23	24	25
Production													
Annual energy (AC kWh)	4,183,650,000	4,162,730,000	4,141,920,000	4,121,210,000	4,100,600,000	4,080,100,000	4,059,700,000	4,039,400,000	4,019,210,000	3,999,110,000	3,979,110,000	3,959,220,000	3,939,420,000
Savings													
Value of electricity savings ($)	699,285,824	715,271,424	731,621,760	748,347,712	765,453,888	782,951,232	800,850,752	819,158,592	837,882,752	857,037,376	876,630,912	896,669,568	917,167,488
Operating Expenses													
Variable cost in $/MWh	58,273,717	59,605,829	60,968,472	62,362,205	63,787,744	65,245,980	66,737,511	68,263,105	69,823,721	71,419,821	73,052,396	74,722,479	76,430,559
Insurance	39,530,269	40,637,116	41,774,956	42,944,654	44,147,105	45,383,224	46,653,954	47,960,265	49,303,152	50,683,640	52,102,782	53,561,660	55,061,386
Property tax	0	0	0	0	0	0	0	0	0	0	0	0	0
Salvage value	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses	97,803,986	100,242,945	102,743,428	105,306,860	107,934,849	110,629,203	113,391,465	116,223,370	119,126,873	122,103,461	125,155,179	128,284,139	131,491,946
Project Debt													
Total installed cost													
Debt amount													
Equity													
Debt payments													
Balance	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest	0	0	0	0	0	0	0	0	0	0	0	0	0
Principal	0	0	0	0	0	0	0	0	0	0	0	0	0
Total P&I Payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-tax cash flow	-97,803,986	-100,242,945	-102,743,428	-105,306,860	-107,934,849	-110,629,203	-113,391,465	-116,223,370	-119,126,873	-122,103,461	-125,155,179	-128,284,139	-131,491,946
After-tax annual costs	-97,803,986	-100,242,945	-102,743,428	-105,306,860	-107,934,849	-110,629,203	-113,391,465	-116,223,370	-119,126,873	-122,103,461	-125,155,179	-128,284,139	-131,491,946
After-tax value of energy generated by system	699,285,824	715,271,424	731,621,760	748,347,712	765,453,888	782,951,232	800,850,752	819,158,592	837,882,752	857,037,376	876,630,912	896,669,568	917,167,488
After-tax cash flow	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Cumulative After-tax Cash Flow	508,104,795	1,123,133,274	1,752,011,606	2,395,052,458	3,052,571,498	3,724,893,527	4,412,352,814	5,115,288,036	5,834,043,915	6,568,977,830	7,320,453,563	8,088,838,992	8,874,514,534
Payback Period Calculation													
Initial investment													
After-tax cash flow	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Debt interest payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only	0	0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow for payback calculation	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Cumulative cash flow	1,182,908,852	1,797,937,330	2,426,815,663	3,069,856,515	3,727,375,554	4,399,697,583	5,087,156,870	5,790,092,093	6,508,847,971	7,243,781,886	7,995,257,620	8,763,643,049	9,549,318,591

Table C: Cash Flow of Large-scale Solar PV Project (Without Incentives)

Large-scale Cash Flow (With incentives)																										
Operating Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Production																										
Annual energy (AC kWh)	0	4,443,020,000	4,420,810,000	4,398,700,000	4,376,710,000	4,354,830,000	4,333,050,000	4,311,390,000	4,289,830,000	4,268,380,000	4,247,040,000	4,225,810,000	4,204,680,000	4,183,650,000	4,162,730,000	4,141,920,000	4,121,210,000	4,100,600,000	4,080,100,000	4,059,700,000	4,039,400,000	4,019,210,000	3,999,110,000	3,979,110,000	3,959,220,000	3,939,420,000
Savings																										
Value of electricity savings ($)	0	534,312,384	546,133,248	558,307,776	570,831,424	583,732,672	596,997,888	610,605,888	624,558,208	638,837,504	653,439,424	668,378,304	683,656,832	699,285,824	715,271,424	731,621,760	748,347,712	765,453,888	782,951,232	800,850,752	819,158,592	837,882,752	857,037,376	876,630,912	896,669,568	917,167,488
Operating Expenses																										
Variable cost in $/MWh		44,430,200	45,445,927	46,484,758	47,547,437	48,634,411	49,746,127	50,883,385	52,046,543	53,236,316	54,453,322	55,698,194	56,971,442	58,273,717	59,605,829	60,968,472	62,362,205	63,787,744	65,245,980	66,737,511	68,263,105	69,823,721	71,419,821	73,052,396	74,722,479	76,430,559
Insurance		28,380,000	29,174,640	29,991,530	30,831,293	31,694,569	32,582,017	33,494,313	34,432,154	35,396,254	36,387,350	37,406,195	38,453,569	39,530,269	40,637,116	41,774,956	42,944,654	44,147,105	45,383,224	46,653,954	47,960,265	49,303,152	50,683,640	52,102,782	53,561,660	55,061,386
Property tax		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salvage value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total operating expenses		72,810,200	74,620,567	76,476,288	78,378,730	80,328,980	82,328,144	84,377,699	86,478,697	88,632,570	90,840,672	93,104,389	95,425,011	97,803,986	100,242,945	102,743,428	105,306,860	107,934,849	110,629,203	113,391,465	116,223,370	119,126,873	122,103,461	125,155,179	128,284,139	131,491,946
Project Debt																										
Total installed cost	5,676,000,000																									
Debt amount	2,838,000,000																									
Equity	2,838,000,000																									
Debt payments																										
Balance		2,838,000,000	2,540,799,493	2,228,738,960	1,901,075,401	1,557,028,664	1,195,779,591	816,468,063	418,190,959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Interest		141,900,000	127,039,975	111,436,948	95,053,770	77,851,433	59,788,980	40,823,403	20,909,548	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Principal		297,200,507	312,060,532	327,663,559	344,046,737	361,249,074	379,311,528	398,277,104	418,190,959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total P&I Payment		439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	439,100,507	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-tax cash flow	-2,838,000,000	-511,910,707	-513,721,074	-515,576,795	-517,479,237	-519,429,487	-521,428,651	-523,478,206	-525,579,204	-88,632,570	-90,840,672	-93,104,389	-95,425,011	-97,803,986	-100,242,945	-102,743,428	-105,306,860	-107,934,849	-110,629,203	-113,391,465	-116,223,370	-119,126,873	-122,103,461	-125,155,179	-128,284,139	-131,491,946
After-tax annual costs	-2,838,000,000	-511,910,707	-513,721,074	-515,576,795	-517,479,237	-519,429,487	-521,428,651	-523,478,206	-525,579,204	-88,632,570	-90,840,672	-93,104,389	-95,425,011	-97,803,986	-100,242,945	-102,743,428	-105,306,860	-107,934,849	-110,629,203	-113,391,465	-116,223,370	-119,126,873	-122,103,461	-125,155,179	-128,284,139	-131,491,946
After-tax value of energy generated by system	0	534,312,384	546,133,248	558,307,776	570,831,424	583,732,672	596,997,888	610,605,888	624,558,208	638,837,504	653,439,424	668,378,304	683,656,832	699,285,824	715,271,424	731,621,760	748,347,712	765,453,888	782,951,232	800,850,752	819,158,592	837,882,752	857,037,376	876,630,912	896,669,568	917,167,488
After-tax cash flow	-2,838,000,000	22,401,677	32,412,174	42,730,981	53,352,187	64,303,185	75,569,237	87,127,682	98,979,004	550,204,934	562,598,752	575,273,915	588,231,821	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Cumulative After-tax Cash Flow	-2,815,598,323	-2,793,196,646	-2,760,784,472	-2,718,053,491	-2,664,701,304	-2,600,398,120	-2,524,828,882	-2,437,701,200	-2,338,722,196	-1,788,517,262	-1,225,918,510	-650,644,596	-62,412,774	539,069,064	1,154,097,542	1,782,975,875	2,426,016,727	3,083,535,767	3,755,857,795	4,443,317,083	5,146,252,305	5,865,008,184	6,599,942,098	7,351,417,832	8,119,803,261	8,905,478,803
Payback Period Calculation																										
Initial investment	5,676,000,000																									
After-tax cash flow		22,401,677	32,412,174	42,730,981	53,352,187	64,303,185	75,569,237	87,127,682	98,979,004	550,204,934	562,598,752	575,273,915	588,231,821	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Debt interest payment		141,900,000	127,039,975	111,436,948	95,053,770	77,851,433	59,788,980	40,823,403	20,909,548	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Less tax on debt interest, Res. Mortgage and Comm. only		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Debt principal payment		297,200,507	312,060,532	327,663,559	344,046,737	361,249,074	379,311,528	398,277,104	418,190,959	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow for payback calculation	-5,676,000,000	461,502,184	471,512,681	481,831,488	492,452,694	503,403,692	514,669,744	526,228,189	538,079,511	550,204,934	562,598,752	575,273,915	588,231,821	601,481,838	615,028,479	628,878,332	643,040,852	657,519,039	672,322,029	687,459,287	702,935,222	718,755,879	734,933,915	751,475,733	768,385,429	785,675,542
Cumulative cash flow	-5,676,000,000	-5,214,497,816	-4,742,985,135	-4,261,153,647	-3,768,700,953	-3,265,297,261	-2,750,627,517	-2,224,399,328	-1,686,319,816	-1,136,114,883	-573,516,131	1,757,784	589,989,605	1,191,471,444	1,806,499,922	2,435,378,255	3,078,419,107	3,735,938,146	4,408,260,175	5,095,719,462	5,798,654,685	6,517,410,563	7,252,344,478	8,003,820,212	8,772,205,641	9,557,881,183

Table D: Cash Flow of Large-scale Solar PV Project (With FiT-0.18 US$/kWh)

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