COST-BENEFIT ANALYSIS OF SOLAR ROOFTOP SYSTEMS TO ACHIEVE THE ALTERNATIVE ENERGY DEVELOPMENT PLAN: AEDP

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Abstract

This study aims to analyse the investment worthiness of residential solar rooftop installation for self-generated electricity and to investigate the feasibility of implementing the government policy for solar-powered houses to achieve success in energy consumption as specified in the Alternative Energy Development Plan 2018–2037 (AEDP 2018). A cost–benefit analysis was conducted by calculating the net present value (NPV), internal rate of return (IRR) and discount payback period (DPB) and analysing the sensitivity based on primary and secondary data. The study compares the investment worthiness of three solar rooftop systems, on-grid, off-grid and hybrid off-grid systems (with both lithium-ion and dry batteries). The findings show that on-grid solar rooftop systems offer the best value for investment while there are risks involved in investing in the off-grid and hybrid off-grid systems with dry batteries as these could lead to large losses due to their high cost and short lifespan. However, replacing dry batteries with lithium-ion ones will create better value for solar rooftop investment. The analysis of the secondary data can be summarised as showing that following the government policy in encouraging the installation of on-grid solar rooftop systems among households with monthly electricity usage of over 500 kWh cannot achieve the AEDP 2018's goal of 10,000 MW power consumption from household on-grid solar rooftop systems by 2037 unless the government sectors instead support and push a policy for the installation of off-grid solar rooftop systems with lithium-ion batteries among households with a minimum monthly electricity usage of 150 kWh.

Keywords: *Alternative energy policy, Cost and benefit analysis, Solar energy, Solar rooftop system*

1. INTRODUCTION

Recently, government and private sectors have emphasised energy conservation measures, and this can be seen from their encouragement of the use of renewable energy and the reduction of energy imports, particularly the installation of solar rooftop systems that generate electricity from solar energy. Since Thailand is located near the earth's equator, it is a suitable place for installing household solar rooftop systems in term of harnessing solar power (Thailand Board of Investment, 2016). Therefore, if the government supports the implementation of a national solar-powered house policy, which promotes residential solar rooftop installations among Thai households, the electricity costs of households will decrease significantly and the use of sustainable energy in Thailand will be enhanced.

Nowadays, in the digital era, the electricity demand of Thai households and industries is extremely high, leading to a dramatic increase in electricity expenses; hence, the installation of solar rooftop systems for electricity generation at home and electricity cost saving have become interesting issues. The efficiency of solar rooftop systems has improved recently, and the costs of installing them have dropped continuously; therefore, installations of household solar rooftop systems are becoming increasingly popular day by day (Tiwngam, 2015). Besides, the Thai Government has raised awareness among Thai citizens at the household level of the need to pay more attention to green energy, especially solar energy, and this perspective is in accordance with the Alternative Energy Development Plan 2018–2037 (AEDP 2018), which supports the installation of on-grid solar rooftop systems among Thai households with a target of 10,000 MW allocated to residential rooftop systems by 2037 (Energy Policy and Planning Office, Ministry of Energy of Thailand, 2019).

Therefore, this national solar-powered house policy is interesting to analyse with the aim of comparing the investment worthiness of installing solar rooftop systems for generating electricity at home and to examine the practicability of conducting the policy for success in energy consumption, as specified in AEDP 2018.

1.1 Purpose of the study

1. To analyse and compare the investment worthiness of solar rooftop installations among three solar rooftop systems: the on-grid, off-grid and hybrid off-grid systems.
2. To examine the practicability of conducting the government policy for solar-powered houses to achieve success in energy consumption as specified in AEDP 2018.

2. METHODOLOGY

2.1 Data collection

The data used in this study, both primary and secondary data, are related to the costs and benefits of investing in household solar rooftop installations, covering three types of solar rooftop system: on-grid, off-grid and hybrid off-grid systems. The primary data were collected via an in-depth interview with Thai residents in Bangkok who have installed a household solar rooftop system and engineers from a household solar rooftop company in Bangkok who have working experience of solar systems, selected through purposive sampling to achieve in-depth, reliable and appropriate data and to fulfil the aims of the study. The scope of the interviews covered customer information, solar system installation costs and the costs of the equipment used in solar rooftop installation. The secondary data are based on academic documents and journals, annual reports and official websites of related organisations (such as the Ministry of Energy, Electricity Generating Authority of Thailand, Provincial Electricity Authority and Department of Alternative Energy Development and Efficiency), and the contexts of the collected data include general information on solar power, solar systems, solar rooftop installations, and the costs and benefits of solar rooftop systems.

2.2 Assumptions of this study

The following assumptions were applied to all the experiments in this research. First, it was assumed that the lifespan of a household solar rooftop project is 25 years. Second, the discount rate equalled 1.46%, in line with the average inflation rate by decade, while the expected returns accounted for 100,000 baht with an expected return rate of 7%, which is in accordance with the minimum loan rate (MLR) basis. Next, the expected payback period was assumed to be 15 years. Then, the electricity prices were calculated based on the 2019 electricity tariffs, Schedule 1 – Residential, of the Metropolitan Electricity Authority. The study assumed that a solar system can generate electricity at an average of five times its system size per day. Next, dry batteries were defined as having a limited shelf life of about three years, but the shelf life of lithium-ion ones is about eight years. The lifespan of inverters was estimated to be ten years, while the shelf life of charge controllers was assumed to be three years. The operation and maintenance (O&M) costs were estimated to increase by 500 baht every ten years, with free services for the first ten years, while solar panel cleaning costs were estimated to rise by 30% every ten years, with free services for the first two years. The costs of inverters could drop by 10% every ten years, while the costs of charge controllers could decline by 10% every three years. The costs of dry batteries were defined as decreasing by 10% every three years, and the costs of lithium-ion ones, with a price of 5,000 baht per 1 kW, were assumed to drop by 10% annually. In the last year of the project or the 25th year, there would be no investments for the equipment and the expenditure on solar system removal could cancel out the salvage value of the solar rooftop completely, so there would be no extra charges for solar system removal.

2.3 Cost–benefit analysis

The cost–benefit analysis was divided into three case studies for the different types of solar rooftop system: the on-grid system, off-grid system and hybrid off-grid system (dry battery and lithium-ion battery). The systems were sorted into four system sizes: 1 kWp, 3 kWp, 5 kWp and 10 kWp.

The net present value (NPV), internal rate of return (IRR) and discount payback period (DPB) are tools used for cost–benefit analysis to analyse an interesting project. They were calculated based on primary and secondary data and were analysed using descriptive analysis, qualitative analysis and quantitative analysis. The estimations of costs and benefits were expressed in monetary terms, so the worthiness of investing in solar rooftop systems could be compared and evaluated and then this analysis could be used for decision making regarding solar rooftop investment.

The net present value (NPV), a value indicating the profitability of a project (Ebrahimi & Keshavarz, 2015), is the difference between the present value of the revenues or benefits and the expenditures or costs over a period of time at the defined discount rate or opportunity cost (Gude, 2018). The NPV (baht) can be calculated using the formula shown in Equation 1, where TB_t is the benefits (baht) and TC_t is the costs (baht) during a single period t (year), when t is in the range of 1 to n; n is the project's useful life (year); and r is the discount rate or opportunity cost (percentage per annum).

$$NPV = \sum_{t=0}^{n}\left[\frac{TB_t - TC_t}{\left(\frac{100+r}{100}\right)^t}\right]$$ ---------------------- Equation 1

If the NPV is lower than the expected returns, it indicates a financial loss from the project; in contrast, investing in the project is assumed to be worthwhile when the NPV is equal to or greater than the predefined profit (Gude, 2018). The higher the NPV is, the larger the return that the project will earn (Ebrahimi & Keshavarz, 2015).

The internal rate of return (IRR) indicates the annual rate of return over the entire life of the project at which the NPV is zero (Belyadi, Fathi & Belyadi, 2017). The IRR can be calculated using the formula shown in Equation 2, and the unit of the IRR is percentage per annum.

$$0 = \sum_{t=0}^{n}\left[\frac{TB_t - TC_t}{\left(\frac{100+IRR}{100}\right)^t}\right]$$ ---------------------- Equation 2

If the IRR is negative, there will be a net loss for the investor when undertaking the project, whereas the project will be profitable if the IRR equals or exceeds the anticipated profit. The more positive the IRR is, the more profit the project will produce (Paltrinieri & Khan, 2016).

The discount payback period (DPB) is the number of years that it will take for the cumulative present value of benefits to equal the cumulative present value of costs at the specified discount rate (Feangthee, Mankeb & Suwanmaneepong, 2019). The DPB can be calculated using the formula shown in Equation 3, where m is the payback period (years).

$$\sum_{t=0}^{m}\left[\frac{TB_t}{\left(\frac{100+r}{100}\right)^t}\right] = \sum_{t=0}^{m}\left[\frac{TC_t}{\left(\frac{100+r}{100}\right)^t}\right]$$ ---------------- Equation 3

If m is greater than the predefined project period or the expected payback period, there will be a financial loss when investing in the project; however, if m is equal to or lower than the acceptable payback period, it can be assumed that the project will be profitable. The shorter the payback period is, the more desirable the project is for investment (Paltrinieri & Khan, 2016).

To measure the worthiness of solar rooftop investments for each case study, the three variables, the NPV, IRR and DPB, need to be considered together. Even if only one variable shows a dissatisfactory result, investors can reject the project as it will not be profitable despite the remaining two variables showing desirable results.

2.4 Sensitivity analysis

The sensitivity of a project is examined by considering the effects of changes in data or significant factors that affect the results of the project analysis, for example by creating advantages, disadvantages, risks or opportunities for the project. The values of the factors used in the cost–benefit analysis of solar rooftop projects were determined in accordance with the defined assumptions; however, in reality, the forecast of the factors' values has to consider some uncertainties that could occur and lead to different results under the same assumptions; otherwise, mistakes would occur in the data analysis.

2.5 The practicability of conducting national policies for solar-powered houses

The Thai Government has established a policy that enhances and supports on-grid solar rooftop installations among Thai households; hence, a household can consume self-generated electricity instead of consuming electricity supplied by electricity providers. According to the Alternative Energy Development Plan 2018–2037 (AEDP 2018), it is expected that a total of 10,000 MW of electricity produced by on-grid solar rooftop systems will be consumed by 2037. This section investigates whether this goal can be achieved by estimating the proportion of Thai households consuming various electricity consumption rates based on the data reported in the 2015 Household Socio-economic Survey of the National Statistical Office of Thailand (2016) together with the study by Chaweewan Denpaiboon (2017) and the Study Project on Housing Demand Forecast of Thailand (2017–2027). This study assumed that there will be no changes in the electricity consumption pattern and proportion of Thai households between 2015 and 2037.

3. RESULTS AND DISCUSSION

3.1 Costs

The main fixed costs of solar rooftop installation include the solar panel costs, equipment costs and labour costs, and the main variable costs are the inverter costs, solar panel cleaning costs, operation and maintenance costs, charge controller costs and battery costs. The significant difference is that two variable costs, the charge controller costs and battery costs, do not arise for on-grid solar rooftop installations, whereas they are applicable to off-grid rooftop installations. The off-grid system is an independent system that can produce power all day; hence, batteries are required to store energy for night-time usage. The prices of batteries and charge controllers are high and vary based on the solar system size. These costs are defined as variable costs because the lifespan of batteries and charge controllers is limited and they need replacement when they have expired; therefore, the costs of the off-grid and hybrid off-grid systems are greater than those of the on-grid system.

3.2 Benefits

Electricity cost saving is the benefit of solar rooftop installations in this study since power generated by a solar system during the daytime will replace the electricity consumed from electricity providers.

Table 1: Annual and monthly electricity cost saving rate of solar rooftop installations by system size

Size of solar system	**Net generation of electricity (kWh)**		**Cost saving rate (baht)**		**Range of household electricity usage (kWh/month)**	
	Monthly	**Annually**	**Monthly**	**Annually**	**On-grid**	**Off-grid and hybrid off-grid**
1 kWp	150	1,800	545	6,540	500–1,499	150–449
3 kWp	450	5,400	1,872	22,464	1,500–2,499	450–149
5 kWp	750	9,000	3,348	40,176	2,500–4,999	750–1,499
10 kWp	1,500	18,000	6,709	80,508	5,000 and over	1,500 and over

A solar system or photovoltaic system can generate electricity for around 5–6 hours per day or 5 times its size. Since a solar system is fixed but the sun moves all the time, the energy accumulation of a solar system cannot reach its full capacity; as a result, it can produce electricity for only 85% of its size. According to Table 1, the larger the system size that is installed, the more electricity costs are saved. Nevertheless, selecting the size of a photovoltaic system depends on the usage of household power in a month. With the same system size, the household electricity usage for the on-grid system is greater than that of the off-grid and hybrid off-grid systems as the power generated by on-grid solar rooftop systems can only be used during the daytime, accounting for 30% of the total monthly power usage. The amount of 1 kWh electricity usage is equal to 1 unit of electricity usage.

3.3 Comparing the investment worthiness of solar rooftop systems through cost–benefit analysis

3.3.1 On-grid system

An on-grid solar rooftop installation is suitable for a household that demands power generated on site for daytime usage but consumes power from electricity providers at night-time and when there is a lack of power during the daytime. The findings in Table 2 show that installing a 1 kWp solar system shows a net loss in solar rooftop investment as the NPV is lower than the expected return, even though the IRR is slightly greater than the anticipated profit and the DPB is shorter than the expected payback period; in contrast, the findings indicate that it is worthwhile investing in installing 3 kWp, 5 kWp and 10 kWp photovoltaic systems. The bigger the system size of a solar system is, the more worthwhile the investment is but the shorter the payback period is.

Table 2: The calculated results of the cost–benefit analysis of on-grid solar rooftop installations

Size of solar system	NPV (baht)	IRR (%)	DPB (year; month)
1 kWp	49,078.77	7.06	13; 0
3 kWp	305,455.61	10.86	9; 2
5 kWp	631,662.78	13.58	7; 8
10 kWp	1,365,711.12	15.62	6; 9

3.3.2 Off-grid system

An off-grid solar rooftop installation is suitable for a household that demands self-generation energy for all-day usage without depending on consuming electricity from power providers at all. The off-grid system requires batteries to store generated power for all-day usage, and the amount of battery storage has to be four times the system size. The greater system size shows the higher loss from solar rooftop investment because the dry batteries are expensive and their replacement is necessary every three years based on their lifespan. Furthermore, if a household solar rooftop system can produce a high amount of electricity, a number of batteries are needed, leading to extremely high costs. Therefore, it is not advisable to invest in the off-grid system with dry batteries in all cases, and the obvious evidence supporting this summary is the negative NPV values in Table 3. However, the costs of the off-grid system can be reduced by using lithium-ion batteries due to their lower price and longer shelf life. The use of lithium-ion batteries creates positive NPV values, as shown in Table 3, indicating the better value of investing in off-grid solar rooftop systems. Focusing on the results in the lithium-ion battery column in Table 3, installing a 5 kWp or 10 kWp solar system is desirable, with the highest positive NPV and IRR values and the lowest DPB values. In contrast, installing a 3 kWp solar system is not worth the investment as the IRR values are somewhat lower than the expected returns, in spite of the moderately positive NPV values and low DPB values. Moreover, installing a 1 kWp off-grid solar rooftop system is not at all worthwhile as it shows the lowest NPV and IRR as well as the longest DPB; however, this case does not make a financial loss because the return rate outweighs the inflation rate slightly, so this case is suitable for investors who prefer indirect benefits and positive externalities, such as using clean energy to lower environmental pollution, to financial benefits.

Table 3: The calculated results of the cost–benefit analysis of off-grid solar rooftop installations

Size of solar system	Dry battery			Lithium-ion battery		
	NPV (baht)	IRR (%)	DPB (year; month)	NPV (baht)	IRR (%)	DPB (year; month)
1 kWp	– 408,592.86	N/A	N/A	8,676.30	2.29	23; 2
3 kWp	–1,067,559.28	N/A	N/A	184,248.20	6.16	14; 10
5 kWp	–1,646,745.98	N/A	N/A	439,599.82	8.30	12; 6
10 kWp	–3,191,106.40	N/A	N/A	981,585.21	9.48	11; 5

3.3.3 Hybrid off-grid system

The hybrid off-grid system is suitable for a household that prefers self-produced energy for all-day usage yet still consumes power from electricity providers as spare power if the household solar rooftop system cannot produce sufficient self-generated electricity. This system requires battery installation, similar to the off-grid system. The costs of the hybrid off-grid solar rooftop system are greater than the costs of the on-grid and off-grid systems since the inverters used in the hybrid off-grid system are specific and more expensive than general inverters. In Table 4, the hybrid off-grid solar rooftop system with a dry battery shows negative NPV values for all solar system sizes, indicating financial losses; hence, this project is rejected for all cases. There are higher monetary losses when the system sizes are larger, showing similar results to the off-grid system with a dry battery. In contrast, for the hybrid off-grid system with a lithium-ion battery, the 5 kWp and 10 kWp solar systems are shown to be financially worthwhile in terms of the NPV, IRR and DPB values, while installing a 3 kWp solar system is not worth the investment due to the low IRR values and high DPB values. In the case of installing a 1 kWp hybrid off-grid system, it is not worthwhile in all terms; however, there is just a small financial loss because the return rate is only slightly lower than the inflation rate. For this reason, it is somewhat acceptable for investors who focus on energy stability. To sum up, the hybrid off-grid system has similar investment worthiness to the off-grid system. Even though the costs of the hybrid off-grid system are the highest, it provides high efficiency, which is perfect for investors who want to eliminate the risk of inadequate power production.

Table 4: The calculated results of the cost–benefit analysis of hybrid off-grid solar rooftop installation

Size of solar system	**Dry battery**			**Lithium-ion battery**		
	NPV (baht)	**IRR (%)**	**DPB (year; month)**	**NPV (baht)**	**IRR (%)**	**DPB (year; month)**
1 kWp	-477,146.03	N/A	N/A	-2,911.21	1.18	N/A
3 kWp	-1,084,112.87	N/A	N/A	167,694.62	5.71	15 ; 7
5 kWp	-1,653,840.38	N/A	N/A	432,505.43	8.17	12 ; 7
10 kWp	-3,204,112.79	N/A	N/A	968,578.82	9.35	11 ; 6

3.4 Sensitivity analysis of investing in solar rooftop systems

3.4.1 Changes in the household electricity consumption rate

When the household power consumption changes, the size of the right solar system will change as well. If the power consumption of a household is lower than the minimum electricity usage of the right solar system size, installing this particular size of solar rooftop system will not earn benefits at all. The minimum household power usage for on-grid solar systems of 1 kWp, 3 kWp, 5 kWp and 10 kWp should be 500 kWh, 1,500 kWh, 2,500 kWh and 5,000 kWh, respectively, while the minimum power usage for households with off-grid and hybrid off-grid solar systems of 1 kWp, 3 kWp, 5 kWp and 10 kWp should be 150 kWh, 450 kWh, 750 kWh and 1,500 kWh, respectively. In contrast, if a household uses electricity exceeding the maximum power usage of the installed solar system size, it will fail to earn the maximum benefits of installing the larger-size solar system.

3.4.2 Changes in costs

When the fixed costs and variable costs decrease, the investment worthiness of solar rooftop systems will increase; however, if these costs rise, the worthiness and benefits of the investment will drop accordingly. Actually, the costs of installing solar rooftop systems in the future will tend to fall consistently since technology developments in photovoltaic cell production, batteries and other equipment lead to lower prices and the installation of household solar rooftop systems has become popular recently, so there is competition in quality, product warranties, customer service, and operation and maintenance services as well as prices. Therefore, if investors consider that installing a solar rooftop system is not worthwhile now, they can slow their project for a while and wait until the costs drop to the optimal point for profitability. According to the study, investing in off-grid and hybrid off-grid solar rooftop systems using dry batteries does not earn financial profits now because the prices of dry batteries need to fall by 95% of the current prices to improve the financial benefits of installing a 3 kWp, 5 kWp or 10 kWp solar systems and by 99% for installing a 1 kWp solar system.

3.4.3 Changes in benefits

Electricity tariffs, Schedule 1 – Residential, of Metropolitan Electricity Authority and Provincial Electricity Authority, tend to increase periodically, leading to higher benefits and worthiness of installing household solar rooftop systems. In contrast, if the future electricity tariffs decrease to lower than the 2018 electricity tariffs, the benefits and worthiness of installing household solar rooftop systems will fall and might become lower than the break-even point. The study indicates that the worthwhile investment of installing on-grid solar rooftop systems of 1 kWp, 3 kWp, 5 kWp and 10 kWp might change to a financial loss if the electricity tariffs drop by 10%, 30%, 50% and 60%, respectively. For the off-grid system with a lithium-ion battery, installing solar rooftop systems sized 3 kWp, 5 kWp and 10 kWp might not be worthwhile if the electricity tariffs decrease by 15%, 35% and 45%, respectively. For the hybrid off-grid system with a lithium-ion battery, the worthwhile investment of installing solar rooftop systems of 3 kWp, 5 kWp and 10 kWp might change to a financial loss if the electricity tariffs fall by 10%, 35% and 40%, respectively.

3.5 Guidelines for conducting national solar-powered house policies

In 2018, the total number of households in Thailand was 21,404,086 (National Statistical Office of Thailand, 2018) and the amount of residential electricity usage in January was equal to 2,517,709.32 MWh or 2,517,709,316.99 kWh (Power Economics Department, Provincial Electricity Authority, 2018). This reflects an enormous usage of residential electricity among Thai households; hence, the Thai Government has put a lot of effort into promoting household solar rooftop projects. According to AEDP 2015, the amount of electricity consumption from renewable energy sources was expected to be 6,000 MW by 2036; however, since more attention has been paid to green energy, the goal specified in AED P2018 was changed to consuming 15,574 MW by 2037, with 10,000 MW for household consumption (Thailand Board of Investment, 2016).

The national solar-powered house policy specified in AEDP 2018 aims to encourage on-grid solar rooftop installations among Thai households and offers four choices of solar system sizes:

1 kWp, 3 kWp, 5 kWp and 10 kWp. Having taken all the factors into account, it can be indicated that, in 2037, installing solar rooftop systems could create a loss for a majority of Thai households, accounting for 93.96% or 19,955,636 households, because they consume less than 500 kWh per month, which is the minimum amount of power usage to create investment worthiness. In contrast, desirable investments in household solar rooftop systems can be created among households installing 1 kWp, 3 kWp and 5 kWp solar systems with an on-grid system, and the number of these households, shown in Table 5, amounts to 1,260,587 (5.94%), 19,817 (0.09%) and 2,825 (0.01%), respectively. No households install 10 kWp since the power usage of a household does not exceed the minimum electricity usage of a 10 kWp solar system.

According to the analysis in the previous paragraph, if this national solar-powered house policy is conducted, only 1,283,229 households will be eligible to participate in this project in 2037, with a total power consumption of 1,334.17 MWp, and far more are needed to achieve the AEDP 2018's goal of 10,000 MWp power consumption. The results are shown in Table 5.

Table 5: Potentiality of Thai households in achieving the AEDP 2018's goal by 2037

Size of solar system	**On-grid system**			**Off-grid and hybrid off-grid systems**		
	Range of household electricity usage (kWh/month)	**Number of households installing solar rooftop systems (household)**	**Total amount of electricity generated by solar rooftop systems (MWp)**	**Range of household electricity usage (kWh/month)**	**Number of households installing solar rooftop systems (household)**	**Total amount of electricity generated by solar rooftop systems (MWp)**
1 kWp	500–1,499	1,260,587	1,260.59	150–449	7,733,708	7,733.71
3 kWp	1,500–2,499	19,817	59.45	450–149	1,175,795	3,527.39
5 kWp	2,500–4,999	2,825	14.13	750–1,499	412,094	2,060.47
10 kWp	5,000 and over	0	0	1,500 and over	22,642	226.42

Here are the guidelines for increasing the amount of power generated on site to reach the AEDP 2018's goal. First, lithium-ion batteries used in off-grid and hybrid off-grid solar rooftop systems should be developed to achieve higher affectivity; as a result, the prices of lithium-ion batteries will be low enough to make the investments in solar rooftop systems worthwhile when installing solar systems following the patterns of this study. When the costs of solar rooftop installation drop, it will be more practical for the Thai Government to conduct the national solar-powered house policy by encouraging the installation of off-grid and hybrid off-grid solar rooftop systems among Thai households with a minimum power usage of 150 kWh per month. If these practices are followed, there will be only 11,894,625.43 households or 56% of the total Thai households creating a loss from investing in solar rooftop installations due to consuming less than 150 kWh of electricity per month. In contrast, worthwhile investments in household power rooftop systems can be created among households installing 1 kWp, 3 kWp, 5 kWp and 10 kWp solar systems, off-grid and hybrid off-grid, and the numbers of these households, shown in Table 5, amount to 7,733,708 (36.41%), 1,175,795 (5.54%), 412,094 (1.94%) and 22,642 (0.11 %), respectively.

According to the analysis in the former paragraph, if the Thai Government follows this suggested policy, installing off-grid and hybrid off-grid solar rooftop systems among Thai households with minimum power usage of 150 kWh per month, the eligible households joining the project will increase to 9,344,239 households in 2037 with power consumption of 13,547.99 MWp, exceeding the target of 10,000 MWp power consumption specified in AEDP 2018. The results are shown in Table 5.

4. CONCLUSION

Installing on-grid solar rooftop systems for residential power production offers the most worthwhile investment. Off-grid and hybrid off-grid solar rooftop systems provide similar levels of investment worthiness when using lithium-ion batteries; nevertheless, the costs of the hybrid off-grid system are slightly greater than those of the off-grid system, yet it offers better efficiency as well, which is suitable for investors who wish to eliminate the risk of inadequate power generation. In contrast, the use of dry batteries in both off-grid and hybrid off-grid solar rooftop systems indicates a financial loss because the prices of dry batteries are extremely high and they require replacement every three years. This finding is in accordance with the study by Jiravusvong (2013), which revealed that investing in energy production from solar energy for household appliances is not worthwhile as the batteries need to be replaced with new ones every five years, leading to high costs. The study by Pojsiri (2016) also supported the findings of this study, showing that projects for on-grid solar rooftop installation in small buildings offer more possibility for investment than off-grid solar rooftop projects. Furthermore, the study by Thongsuk and Ngaopitakkul (2018) found that installing an on-grid solar rooftop system offers the most worthwhile investment as it provides acceptable return rates.

The AEDP 2018's goal, consuming 10,000 MW or 10 GW of electricity produced from households' on-grid solar rooftop systems by 2037, cannot be achieved if Thai households follow this policy strictly; however, this national solar-powered house policy can lead to success when encouraging Thai households to install off-grid and hybrid off-grid solar rooftop systems instead; hence, the target of power consumption specified in the AEDP 2018 will be exceeded. Besides, the government should support the development of lithium-ion batteries; therefore, their prices will fall significantly and, consequently, the costs of installing off-grid and hybrid off-grid solar rooftop systems will drop as well, and this is desirable for investment in this type of project. The results of this analysis are in line with the study by Goel (2016), which revealed that many countries worldwide, such as India, are aware of pollution issues and are creating many policies to enhance photovoltaics, especially solar rooftop power generation, which can satisfy enormous residential power needs. In addition, the Indian Government should support tax benefits and create measures for household solar rooftop installations.

The significant difference between this study and other studies in terms of the literature review is that this study compares the investment worthiness of three solar rooftop systems – on-grid, off-grid and hybrid off-grid – by considering the actual fixed costs and variable costs over the project period as well as calculating the discount payback period. There are comparisons between costs of dry batteries and lithium-ion ones; hence, this study can be useful for further studies and applications when the efficiency of batteries used in solar rooftop systems is improved in the future. Moreover, this study provides practical guidelines for conducting the national solar-powered house policy; therefore, they can be implemented effectively in public policy.

However, the findings of this study are the results from a cost–benefit analysis based on defined assumptions. In reality, the investment worthiness for individuals usually varies depending on their personal circumstances, which can change due to changes in the environment, the value of expected returns, the anticipated return rates, the payback period and the individual risk acceptance.

5. RECOMMENDATIONS

It is suggested that the government should establish projects or measures based on the national solar-powered house policy that can enhance and support installations of household solar rooftop systems for self-generation of electricity through on-grid, off-grid and hybrid off-grid systems. Concrete examples of this approach are training projects to provide knowledge about household solar rooftop systems, a low-interest loan scheme for household solar rooftop installation, tax deduction for households installing solar rooftop systems and support for solar cell SMEs. These projects can lead to direct and indirect benefits. The direct benefits are reduced costs related to solar rooftop systems among Thai households and a more sustainable electricity supply in Thailand, while the indirect benefits include stimulating the economy and reducing the environmental pollution. Nonetheless, the right solar system sizes need to be considered for proper application in each household when installing residential solar rooftop systems, and this study could provide a reference for this circumstance. Using an oversized solar system will produce more energy than needed, leading to unnecessarily high costs, while installing too small a home solar system will result in insufficient power generation for a household with an off-grid system, but this does not affect the installation of on-grid and hybrid off-grid rooftop systems as these systems can adjust by using power supplied by electricity providers instead.

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