A COMPARATIVE ASSESSMENT OF SELF-CONSUMPTION SUPPORT SCHEMES FOR ROOFTOP PV SYSTEMS IN THAILAND

Miss Kespanerai Kokchang

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for the Degree of Doctor of Philosophy Program in Environment Development and Sustainability
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การประเมินเชิงเปรียบเทียบของมาตรการส่งเสริมการผลิตไฟฟ้าเพื่อใช้เองสำหรับระบบผลิตไฟฟ้าพลังงานแสงอาทิตย์บนหลังคาในประเทศไทย

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บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2560

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By	Miss Kespanerai Kokchang
Field of Study	Environment Development and Sustainability
Thesis Advisor	Sopitsuda Tongsopit, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Doctoral Degree

________________________________ Dean of the Graduate School
(Associate Professor Sunait Chutintaranond, Ph.D.)

THESIS COMMITTEE

________________________________ Chairman
(Associate Professor Dawan Wiwattanadate)

________________________________ Thesis Advisor
(Sopitsuda Tongsopit, Ph.D.)

________________________________ Examiner
(Assistant Professor Surachai Chaitusaney)

________________________________ Examiner
(Sujitra Vassanadumrongdee, Ph.D.)

________________________________ External Examiner
(Wichsinee Wibulpolprasert, Ph.D.)

เกษพรรณราย เกาะช้าง : การประเมินเชิงเปรียบเทียบของมาตรการส่งเสริมการผลิตไฟฟ้าเพื่อใช้เองสำหรับระบบผลิตไฟฟ้าพลังงานแสงอาทิตย์บนหลังคาในประเทศไทย (A COMPARATIVE ASSESSMENT OF SELF-CONSUMPTION SUPPORT SCHEMES FOR ROOFTOP PV SYSTEMS IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ดร. โสภิตสุดา ทองโสภิต, 143 หน้า.

การเติบโตอย่างรวดเร็วของระบบผลิตไฟฟ้าพลังงานแสงอาทิตย์ (Solar photovoltaic) ได้รับการสนับสนุนอย่างต่อเนื่องทั่วทุกมุมโลก และได้มีการถกเถียงเกี่ยวกับอนาคตของนโยบายสนับสนุนและกฎระเบียบเพื่อรองรับการเพิ่มขึ้นของระบบรูฟท็อปโซลาร์ในอนาคต สำหรับประเทศไทยซึ่งเป็นหนึ่งในผู้นำด้านการลงทุนระบบพลังงานแสงอาทิตย์ในภูมิภาคเอเชียตะวันออกเฉียงใต้ ได้มีการเปลี่ยนกรอบนโยบายเพื่อสนับสนุนการติดตั้งระบบรูฟท็อปโซลาร์แบบกระจายตัวขนาดเล็ก จากการสนับสนุนของภาครัฐในรูปแบบ FiT นำไปสู่รูปแบบนโยบายที่มุ่งเน้นการผลิตไฟฟ้าเพื่อใช้เอง (Self-consumption) ซึ่งประกอบไปด้วยสามรูปแบบที่เป็นไปได้ ได้แก่ Net metering, Net billing และ รูปแบบการผลิตไฟฟ้าเพื่อใช้เอง โดยไม่มีการชดเชยค่าไฟฟ้าส่วนเกิน (Self-consumption only) Net metering และ Net billing เป็นนโยบายชดเชยค่าไฟฟ้าส่วนเกินที่เกิดขึ้นจากแหล่งพลังงานของผู้บริโภคโดยเฉพาะระบบรูฟท็อปโซลาร์ โดยวิทยานิพนธ์ฉบับนี้เล็งเห็นว่า การออกแบบองค์ประกอบของรูปแบบสนับสนุนการผลิตไฟฟ้าเพื่อใช้เองจากการศึกษามุมมองของผู้มีส่วนได้ส่วนเสียนั้นมีความสำคัญ ประกอบกับการคำนวณความคุ้มทุนเชิงเศรษฐศาสตร์ของระบบรูฟท็อปโซลาร์ภายใต้รูปแบบการสนับสนุนระบบผลิตไฟฟ้าเพื่อใช้เอง และ รูปแบบการชดเชยไฟฟ้าส่วนเกิน และเพื่อเพิ่มความมั่นใจในการดำเนินนโยบายได้อย่างมีประสิทธิภาพ ได้นำมาสู่จุดประสงค์ของวิทยานิพนธ์ฉบับนี้คือ เพื่อมุ่งเน้นการวิเคราะห์เชิงเศรษฐศาสตร์ภายใต้รูปแบบการผลิตไฟฟ้าเพื่อใช้เองสำหรับภาคครัวเรือนและภาคอาคารพาณิชย์ภายใต้ 3 รูปแบบที่เลือกใช้ในงานวิจัยฉบับนี้ดังนี้ 1). รูปแบบการผลิตไฟฟ้าเพื่อใช้เองของโครงการนำร่องโซลาร์รูฟท็อปเสรี (Thailand's self-consumption scheme), 2). รูปแบบการผลิตไฟฟ้าเพื่อใช้เองและชดเชยไฟฟ้าที่ผลิตได้ส่วนเกิน โดยสามารถสะสมเครดิตในรูปหน่วยไฟฟ้าภายในระยะเวลาที่กำหนด และสามารถซื้อเครดิตคืนภายหลังจากหมดระยะเวลาสะสม (Net metering with rolling credit and buyback และ 3). รูปแบบการรับซื้อคืนไฟฟ้าส่วนเกินทันที (Net billing with real-time buyback) โดยสามรูปแบบนี้จะนำมาเปรียบเทียบความคุ้มทุนเชิงเศรษฐศาสตร์ของการติดตั้งระบบรูฟท็อปโซลาร์ของภาคครัวเรือน และภาคอาคารพาณิชย์ โดยการคำนวณหาค่า Net Present Value, Payback period, และ Internal Rate of Return นอกจากนี้เพื่อเพิ่มความเข้าใจของรูปแบบนโยบายที่เลือกใช้ในงานวิจัย จึงได้ประเมินปัจจัยทางเทคนิคเพื่อวิเคราะห์ปัจจัยสนับสนุนหรืออุปสรรคที่อาจเกิดขึ้น โดยการทบทวนข้อกำหนดการเชื่อมต่อระบบโครงข่ายไฟฟ้าของประเทศไทย และข้อกำหนดการติดตั้งมิเตอร์ในการดำเนินการติดตั้งระบบรูฟท็อปโซลาร์และประกอบกับการศึกษามุมมองของผู้มีส่วนได้ส่วนเสียในการออกแบบรูปแบบสนับสนุนการติดตั้งระบบรูฟท็อปโซลาร์ในอนาคต ซึ่งผลการศึกษาจากมุมมองของผู้มีส่วนได้ส่วนเสีย พบว่า กลุ่มผู้มีส่วนได้ส่วนเสียส่วนใหญ่ เลือกรูปแบบการชดเชยไฟฟ้าส่วนเกิน ในรูปแบบ Net metering ซึ่งสอดคล้องกับผลการศึกษาด้านเศรษศาสตร์ที่ รูปแบบ Net metering with rolling credit and buyback มีความคุ้มทุนเชิงเศรษฐศาสตร์ต่อภาคครัวเรือน และภาคอาคารพาณิชย์มากที่สุด สุดท้ายนี้วิทยานิพนธ์ฉบับนี้ได้นำเสนอข้อเสนอแนะเชิงนโยบายสำหรับแต่ละกลุ่มของผู้มีส่วนได้ส่วนเสีย เพื่อเพิ่มความเข้าใจในการมีส่วนร่วมในรูปแบบนโยบายการสนับสนุนการติดตั้งระบบรูฟท็อปโซลาร์แบบยั่งยืนสำหรับภาคครัวเรือนและภาคอาคารพาณิชย์ของประเทศไทยต่อไป

สาขาวิชา สิ่งแวดล้อม การพัฒนา และความยั่งยืน	ลายมือชื่อนิสิต ....
ปีการศึกษา 2560	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

5787803020 : MAJOR ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY
KEYWORDS: SELF-CONSUMPTION SCHEMES / ROOFTOP SOLAR PV SYSTEM / ECONOMIC FEASIBILITY

KESPANERAI KOKCHANG: A COMPARATIVE ASSESSMENT OF SELF-CONSUMPTION SUPPORT SCHEMES FOR ROOFTOP PV SYSTEMS IN THAILAND. ADVISOR: SOPITSUDA TONGSOPIT, Ph.D., 143 pp.

The growth in the adoption of solar photovoltaic (PV) power generation systems has been accelerating around the world, contributing to the debate about the future of policy and regulation in a high distributed energy resources future. Thailand is one of the leaders in solar investment in Southeast Asia. It has recently shifted its policy framework from subsidizing power export through feed-in tariffs toward a policy that is focused on supporting self-consumption of PV electricity. There are three possible forms of self-consumption support scheme: net metering, net billing, and self-consumption only. Net metering and net billing are electricity policies to assign compensation to excess electricity generated from the prosumers' sources, particular in rooftop solar PV system. The design elements on new self-consumption scheme from perspectives of various stakeholders together with the assessment of economic feasibility of rooftop PV system under self-consumption schemes can help to ensure successful implementation of the policy. It is important to analyze the possible impacts of rooftop PV system on distribution network system.

This dissertation consists of three main components: economic feasibility analysis, technical analysis, and stakeholders' perspectives analysis. First, this study assesses the economic feasibility of residential and commercial sectors on rooftop solar PV systems under Thailand's self-consumption scheme, net metering with rolling credit and buyback scheme, and net billing with real-time buyback scheme. These three schemes are compared using 3 indicators: Net Present Values (NPV), Payback Period (PB), and Internal Rate of Return (IRR) to assess the feasibility of rooftop solar PV investment for consumers. To supplement the understanding of selected schemes, this research assesses the technical factors that support or hinder the implementation of solar PV rooftop by reviewing Thailand's grid code and meter requirement of rooftop solar PV installation. Third, this study investigates the perspectives of stakeholders on the detailed design options of self-consumption schemes for supporting rooftop solar PV system installation. When combined the outcomes of stakeholder's perspectives, the result also shows that most of stakeholder groups prefer a strong desire to compensate for excess generation from rooftop PV system in the form of net metering. This finding corresponds to the economic feasibility analysis, which indicate that net metering with rolling credit and buyback is economically feasible for both residential and commercial sectors. Finally, this dissertation suggests policy recommendations for each group of stakeholders in order to increase their understanding on how to contribute to a sustainable scheme to scale up rooftop solar PV installation for both residential and commercial customers in Thailand.

Field of Study:	Environment Development and Sustainability	Student's Signature	....
Academic Year:	2017	Advisor's Signature	....

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CHAPTER 1
INTRODUCTION

1.1 Background and importance of the study

Energy is fundamental for economic development of society. Global demand for energy continues to rise, reflecting an expanding global economy, rapid industrialization, population growth, urbanization, and improved energy access (Ramírez et al., 2017). The rapid rise in demand for energy has brought adverse impacts for society, the economy and, the environment due to heavy reliance on fossil fuels and the resultant increase in global carbon emissions of more than 16 times over the last century (IRENA, 2017; Karatayev et al., 2016; Ren21, 2017; Wilkinson et al., 2007)The need for renewable energy in order to cope with this ever growing urban sprawling and world population proliferation is crucial to curb environmental degradation. The adverse impact on environment is becoming more apparent in the developing nations, particularly in the ASEAN Region. According to (Dahiya, 2016) from 1950's to 2014, with more than 1000% rise of its urban inhabitants, the ASEAN Region has undergone enormous urbanization growth. This phenomenon has implicated an urban consumer society, thus further leading to increasing energy demand and consequently carbon emissions to the atmosphere. One of the key solutions is to introduce renewable energy at micro scale such as within the community or households' level and to make this micro-scale investment feasible (Dincer, 2000; Panwar et al., 2011; Ren21, 2017). Solar photovoltaic (PV) rooftop systems have been widely used for producing electricity in the residential and commercial sectors. In addition, it can help reduce the amount of conventional energy usage and help lower greenhouse gas emissions as the lifecycle carbon emissions of solar systems are one of the lowest when compared against other power generation technologies (Kittner et al., 2013; Ren21, 2017).

Increasing popularity of distributed energy resources, particularly solar photovoltaic technology, has induced the transition of policy and regulatory schemes to encourage self-production and self-consumption by electricity users. During the past decades, the installed photovoltaic (PV) capacity has been growing due to the falling cost of solar PV panels and support schemes that promote the installation of solar PV worldwide (Dehler et al., 2015; Masson et al., 2016; Prol et al., 2017; Ren21, 2017). The global total installed capacity in 2015 was 227 GW, a 25% increase over 2014 (PVPS, 2015). The majority of all PV installation worldwide is grid-connected systems, which have the advantage of more efficiently utilization of generated power (Eltawil et al., 2010; Masson et al., 2016)

Among emerging economies, Thailand is the leader in solar PV investment. And though the majority of such investment has been for utility-scale systems, the government has recently shifted the support toward smaller-scale, distributed solar PV systems (Tongsopit et al., 2017). The Thai government began to promote the use of rooftop PV for exporting power between 2013 and 2015 and for self-consumption since 2016 onwards. In 2016, Thailand launched a Rooftop solar PV Pilot project, designed for self-consumption in residential and commercial buildings. The pilot project allowed consumers to produce electricity from their rooftop solar PV systems, and excess electricity that is not consumed will flow back to the power grid without any compensation by the utilities (DEDE, 2016; GIZ, 2017). The government was currently designing a support scheme on how to support rooftop solar PV systems for self-consumption. The details of the support scheme would have an impact on how consumers produce and use distributed solar PV systems in the future.

Thailand’s self-consumption scheme distinguishes between self-consumed and excess generated electricity. Self-consumed generation (generation used for local consumption at the time of generation) will be valued at the local retail rate of electricity. Excess generation fed back into distribution grid at the time of generation and that part of excess generation can be compensated in the forms of net metering and net billing. These two schemes are electricity policies that assign compensation to excess electricity generated from the prosumers' sources, particular for rooftop solar PV system (Dufo-López et al., 2015; Koumparou et al., 2017). Net metering has been widely used in many countries and has attracted the attention from various stakeholders such as policymakers, private companies, and decision makers (Christoforidis et al., 2016). It offers an alternative option to gain revenue from small scale PV generation, especially household sector (Poullikkas, 2013; Yamamoto, 2012). Net billing is an alternative approach to net metering. Like net metering, prosumers are able to offset retail electricity purchases under net billing. The main difference between net metering and net billing is the number of meters and the value of excess electricity. Net metering uses a bi-directional meter that is able to run backward and forward, measuring the value of excess electricity in energetic compensation (kWh). By contrast, net billing uses two meters or two registers in one meter or either one (Eid et al., 2014) to measure imported and exported electricity separately; thus the value of excess electricity is measured in monetary compensation (Masson et al., 2016). In this regard, this study used a definition of Thailand's self-consumption scheme as the policy in order to encourage the installation and application of rooftop solar PV systems targeted at residential sectors. This scheme basically works in a way of where the consumed electricity generated using rooftop PV system will offset the used electricity that would otherwise have to be bought from the power grid. The term "prosumers" referred to the energy consumers who both consume the electricity from the grid and have the ability to produce their own power from a range of different onsite generators such as rooftop solar photovoltaic systems (Eid et al., 2014).

Up to this date, the development in current Thailand's self-consumption scheme has less of rigorous analyses and drawn on insufficient evidence-based studies in terms of the potential costs and benefits for different stakeholders. Thus, this research is to assess the economic feasibility of residential and commercial rooftop PV systems under self-consumption schemes, including Thailand's self-consumption scheme, net metering and net billing schemes and to investigate the drivers and barriers that are associated with each type of net metering schemes. In enhancing the further understanding of the self-consumption schemes, this research also assesses the technical factors associated with each type of self-consumption schemes and investigates the stakeholder's perspectives on each element of rooftop solar PV schemes in order to help the future design support for rooftop solar PV policy in Thailand.

1.2 Objectives of the study

The objectives of this study are:

1.2.1 To compare the economic feasibility of self-consumption schemes for residential and commercial rooftop PV customers and analyze the barriers associated with each type of scheme in Thailand.

1.2.2 To analyze the technical factors that support or hinder under Thailand self-consumption scheme.

1.2.3 To investigate the perspectives of stakeholders on the detailed design options of self-consumption schemes for supporting rooftop solar PV systems in Thailand.

1.3 Research questions

To fulfill objectives, the study mainly addresses four appropriate research questions:

1.3.1 Are various self-consumption schemes feasible from the perspectives of residential and commercial rooftop solar PV system owners?

1.3.2 What are the technical factors that support or hinder the implementation of Thailand self-consumption scheme?

1.3.3 How did different stakeholders perceive various options of self-consumption schemes?

1.3.4 What should be an appropriate self-consumption scheme?

1.4 Scope of the study

1.4.1 This research conducted an economic feasibility and associated barriers with each type of self-consumption schemes by focusing on residential and commercial customers.

1.4.2 This research reviewed the technical factors that may support or hinder Thailand’s self-consumption scheme from Thailand’s grid code and meter requirement of rooftop solar PV installation.

1.4.3 This research investigated the stakeholders' perspectives on the new self-consumption schemes. The stakeholders' perspectives, including views from consumers, private companies, policymakers, and distribution utilities.

1.5 Operational definitions

1.5.1 **Solar photovoltaic (PV) rooftop system**: A solar photovoltaic rooftop system refers an electrical device installation of solar PV modules on a rooftop, which converts solar energy to electricity by the photoelectric effect. It mainly consists of solar panels to absorb and convert sunlight to electricity, solar inverters to invert the electrical current from DC to AC, mounting and other accessories to complete the system's installation set-up.

1.5.2 **Prosumers**: Home owners or building owners who installed solar photovoltaic systems on their rooftops. They both consume electricity from the grid and produce electricity to meet their energy consumption or provide electricity within distributed network. They can receive compensation from their electricity generated through their reduced electricity consumption bills (Eid *et al.*, 2014).

1.5.3 **Economic feasibility**: An economic analysis that assesses both benefits and costs and calculates the net impact of a project in the form of Net Present Values (NPVs), Internal Rate of Returns (IRRs) and Payback Period (PB).

1.5.4 **Self-consumption scheme**: A mechanism for treating PV generate electricity firstly used for local consumption in a house or in a building and if there is excess generation of PV electricity injected back to the grid, will be gained no compensation.

1.5.5 **Net metering**: This scheme allows prosumers to gain the compensation from the excess part of the electricity as the credits at the retail rate and allows excess part of electricity can be banked more than one billing period, typically within twelve months. If there are leftover credits at the end of banking period, the prosumers can gain payment at wholesale rate, retail rate, or premium rate.

1.5.6 **Net billing**: Net billing is a variation of net metering that uses two one-directional meters or one meter with two data-records, keeping the measured consumption from the grid and the excess injected into the grid in separate records, valuing them separately and at a different price (Watt et al., 2015).

1.6 Significance of the study

This research recommended the most appropriate self-consumption schemes for supporting the deployment of rooftop solar PV systems in Thailand based on the analysis of the perspectives of each stakeholder group on the desirable elements of the self-consumption schemes. The researcher realized that the role of stakeholders in rooftop solar PV policy development is important for promoting rooftop solar PV system in Thailand. Since energy transition policy from conventional energy sources to renewable energy sources may result in profound consequences for the utilities, the economic feasibility for the consumers and private company. Another significance of this research was to provide the technical support and to remove related obstacles which may occur in implementing rooftop solar PV installation, thus, the policymaker and utilities could identify and provide solutions in order to come out with the most sustainable and attractive self-consumption schemes of rooftop solar PV installations. This research significantly endeavored and contributed in promoting the deployment of self-consumption scheme to policymakers, electricity authorities, and consumers in Thailand.

1.7 Expected outcomes

1.7.1 Evidence-based documentation on the economic feasibility of different self-consumption schemes.

1.7.2 Increased understanding on the methodology for the design of a sustainable scheme and to scale-up solar photovoltaic rooftop installation for both residential and commercial customer

CHAPTER 2
LITERATURE REVIEW

2.1 Solar technology and sustainable energy

Sources of energy from conventional fossil fuel resources such as oil, natural gas, and coal have proven as an effective catalyst and driver for economic development, but the drawback could permanently degrade the environment and harm to human health. The compromise environment and social dimension within sustainable concept create imbalance development, thus it needs to be halted and avoided in order to achieve a balance development growth. The key to sustainable future is to use renewable energy such as solar, wind, bio-mass and other renewable sources (Jacobson et al., 2009; Prakash et al., 2009). The used or renewable energy sources show that the decreasing trends of total greenhouse gases emission in different years, the implementation of renewable energy systems which is exponentially increasing in certain development particularly in developed and developing countries proven a positive discourse in sustainable development agendas (Dusonchet et al., 2010; Ren21, 2017).

In regard to Sustainable Development Goals (SDGs), renewable energy is the sustainable key that placed as goal number 7 for ensuring access to affordable, reliable, sustainable and modern energy for all besides the 17 goals as shown in Figure 1 (IRENA, 2017; UN, 2016). The proposed goals and targets are consistent with SE4all's (Sustainable Energy for all) objectives on energy access, efficiency and renewable energy. According to the Brundtland Report of the World Council on Economic Development, sustainable development is "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Bruntland, 1987)

Figure 2.1: Linkages between Goal 7 and SDGs
Source: (IRENA, 2017)

Renewable energy has considerably shifted global perception during the last decades and it has become the mainstream sources of alternative's energy, which is supported by policies and targets. The three objectives of SE4all's are set to be achieved by 2030, including double the global share of renewables, double the global rate of improvement in energy efficiency and ensure to access clean and sustainable energy for all people. Many countries have taken actions by passing laws and regulations to promote renewable energy in power generation in order to combat climate change, reduce the use of fossil fuels, create resilient energy system and enhance economic growth (Nakada et al., 2014; Nilsson et al., 2013).

To limit the global temperature rise, renewable energy deployment must be scaled up especially in power sector. Among renewable energy technologies, solar photovoltaic (PV) has become the leading technology for investment and popular in the market nowadays. This is due to continuous cost reductions ((Fu et al., 2016)IRENA 2017). In addition, solar PV has grown faster in terms of capacity and output. Subsequently, solar PV could increasingly be comparatively cost-competitiveness against conventional fossil fuels. In addition, the use of solar panel technologies not only could increase the efficiency to generate power, but also enhance the environmental benefits in terms of reducing GHG emissions. Solar PV technology mainly converts energy from radiation directly into electricity. Typically, PV system has three main components, including PV modules, inverter and balance-of-system (BOS) components (e.g. box, transformer, and meter) (Joe Simon, 2013).

Solar PV deployment has increased progressively for almost two decades, from less than 9 gigawatt (GW) installed capacity in which combined year to over 290 GW in 2016 (IRENA, 2017). Grid-connected PV systems account for nearly 99% of the PV installed capacity compared to stand-alone systems (using batteries). A grid-connected system is connected directly to the electric grid which in most case is the public electricity grid and feeds power into the grid. They would be varying in sizes from a few kWp for residential purpose to solar power plants up to ten of GWp (Parida et al., 2011)

Another important advantage of the advancement of solar photovoltaic is job creation mainly in China, Japan, the United States, Bangladesh, and India. The number of global employment in solar PV has increased by 12% in 2016 for both manufacturing and installation sectors. Besides, the main manufacturing hubs are in Asia, which China is the leader in manufacturing, followed by Malaysia, the Republic of Korea and Thailand (IRENA, 2017).

While solar PV are gaining attention due to many driven factors as mentioned above, the policy mechanism to promote the use of solar PV are very crucial. Several countries have made progress in the transition from the feed-in-tariff (FiT) schemes toward self-consumption schemes such as Germany (Haas et al., 2004; Klein et al., 2008; Masson et al., 2016). Net metering is one form of self-consumption as financial support mechanism that in implemented in many countries ((Christoforidis et al., 2016)). Since the development of grid-connected PV has been implemented in several countries by different programs, net-metering is one of the policy incentive to stimulate the installation of grid-connected PV generators that owned by the consumer of electricity. In the net metering system, the electricity fed into the grid is preferably valued at the same as that consumed from the grid (retail price); basically, including simple with buy-back, with rolling credit or with buy-back and rolling credit (N. Darghouth et al., 2013; N. R. Darghouth et al., 2014; De Boeck et al., 2016; Eid et al., 2014). In this regard, the definition and schemes of net metering will be reviewed intensively in the next section.

2.2 Self-consumption policies for rooftop PV installation

Self-consumption policies have been promoting in several developed countries and developing countries. A self-consumption scheme can be defined as a scheme that encourage the PV generated electricity to be firstly used for local consumption in a house or in a building in order to reduce electricity bills, and all this electricity that injected into distribution grid will gain no compensation (Luthander et al., 2015; Masson et al., 2016; Prol et al., 2017). Self-consumption schemes can be distinguished into two broad categories: Net metering and Net Billing. The terms "net-metering" and "net-billing" are sometimes used interchangeably. Net metering and net billing are electricity policies that assign compensation to excess electricity generated from the prosumers' sources. The term "prosumers' refer to the energy consumers who both consume the electricity from the grid and have the ability to produce their own power from a range of different onsite generators, such as rooftop PV system. However, the main differences between net metering and net billing include the value of excess of electricity, the number of register (meter) and the compensation terms (in kilowatt-hour (kWh) and in monetary unit), as discussed in the following sections. Net-metering allows the meter of the prosumer who has installed a rooftop solar PV system to spin backward during the moments when the PV electricity is fed back into the grid. This "excess electricity" is hence valued in energy terms and the same price as the electricity that the prosumer buys from the grid (retail price) (Eid et al., 2014).

Hughes and Bell (2006) categorized the different schemes of net metering into two broad groups: net metering with a single or bi-directional meter for recording the prosumer (consumer and producer)'s electricity consumption at the start and the end of billing period. Bi-directional metering represents electricity metering in two directions, which are consumption and production. The meter will "run backward" when prosumers' production exceeds the demand and feeds electricity to the grid. In the policy context, one study defined net metering as a method by which prosumers can offset for their electricity production through their reduced electricity consumption bills (Eid et al., 2014). Net metering works by using a meter that is able to spin and record energy flow in two directions. The meter will spin forward when the prosumer uses electricity from the grid and spin backward when energy is being fed back into the grid (Mir-Artigues, 2013)

As an example of a national scheme (Holdermann et al., 2014), the National Regulatory Agency for Electricity (ANEEL) in Brazil introduced net metering as an incentive mechanism for renewable energy use and allows the consumer unit to subtract the self-produced energy from its measured consumption. If surplus generation, the electric energy is fed back to the grid, which serves as energy storage. When a consumer unit's electricity consumption is higher than the production, the consumer unit is permitted to draw electricity from the grid. The generated and injected energy is subtracted from the amount of electricity consumed from the grid in forms of electricity credits (in kWh), not monetary unit. If the production of energy is greater than the consumption during the account period, the overproduction is credited to the next month. The credits will be valid for 36 months. In the case of higher consumption than self-generation, the negative balance must be paid by the customer unit in the form of the prevailing electricity tariff. The monthly electricity bill provides the consumer unit with the balance information. The consumer will be able to compensate for a negative future balance by the surplus generation in the present. In addition, it is allowed to unite several consumer units if they are registered under the same taxpayer identification number (CPF), or with the same corporate taxpayers' registration number in case of companies (CNPJ). (ANNEL, 2012, as cited in Holdermann et al., 2014).

Net metering has been using for decades in the U.S. and some states in Canada (Ontario, Prince Edward Island, Quebec) (Ackermann et al., 2001). Net metering uses only one single bi-directional meter, which allows electricity to run forward and backward by measuring imported minus exported energy in kWh and record the amount of electricity banked.

Net billing is an alternative mechanism to net metering. Net billing uses two meters register to measure imported and exported electricity separately; thus the value of excess electricity is measured in monetary compensation. The rate of excess part of electricity that is fed back into the grid can be valued in different prices such as below, equal, or above retail rate. Table 2.1 summarizes the main difference of compensation schemes and their properties. For most cases, net billing's rate of excess electricity is valued below the retail rate such as in Chile and Spain (Masson et al., 2016). The mechanism for which the "excess electricity" is compensated can be varied depending on the policy and regulation of each country and can have a strong effect on the feasibility of the PV systems (Dufo-López et al., 2015).

Table 2.1: Summary the main differences of self-consumption schemes

Criteria	**Thailand's Self-consumption scheme**	**Net metering**	**Net billing**
Number of registers	2	1	2
Value of excess generation	No compensation	Energetic compensation (Credit in kWh)	Monetary compensation (credit in monetary unit)
Billing period	Monthly	Monthly	Monthly
Buyback rate		Flexible rate (below, equal, or above retail rate)	Flexible rate (below, equal, or above retail rate)
Compensation timeframe	-	Monthly	hourly
Rolling credit	-	In (kWh)	In (Monetary)
Banking period	-	Yearly	Yearly

Source: (Dufo-López et al., 2015; Hughes et al., 2006; Masson et al., 2016)

This research categorizes net metering and net billing schemes according to the definitions used by Hughes and Bell (2006), Dufo-López and Bernal-Agustín (2015) as described below:

2.2.1 Net metering schemes

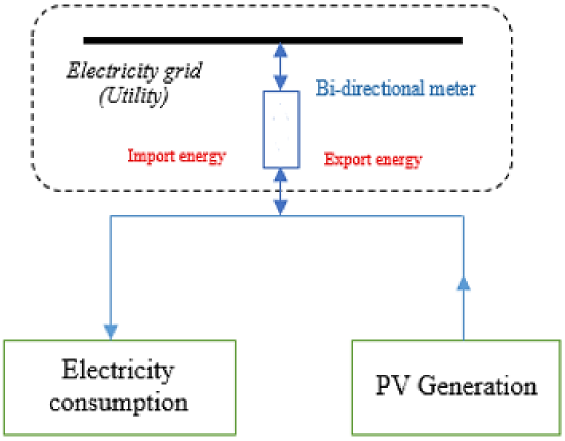

Figure 2.2 Concept of net metering scheme

Source: Adapted from (Dufo-López et al., 2015; Nikolaidis et al., 2017)

Figure 2.2 represents the concept of net metering scheme; this scheme uses a single bidirectional meter to record the cumulative amount of imported and exported electricity. The electricity that exported to the grid has the same value (retail rate) as the electricity imported from the grid. Net metering schemes can be categorized into four types as follows:

2.2.1.1 Simple net metering

The first scheme is simple net metering that generally uses a single, bi-directional meter to record the amount of electricity consumed. The billing period in this scheme is usually one or two months. In this scheme, there is no compensation if prosumer generates more electricity than the load. But, the compensation will be credited in the form of kWh, as shown in Figure 2.3.

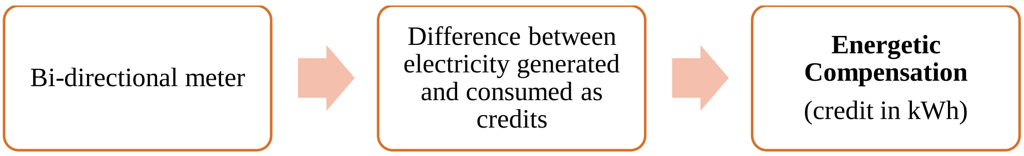

Figure 2.3: Simple net metering diagram

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.1.2 Net metering with buy back

This scheme is the extension of simple net metering, in which the utility will pay the prosumer for any excess electricity generated during the billing period. As shown in the Figure 2.4, the compensation of excess electricity will be paid monthly. In this case, value of excess electricity will be applied as monetary compensation (credit in monetary unit) at the end of the month, which can be valued at below retail rate (avoided cost of the utility), retail rate (buy the same rate as prosumers pay), or above retail rate (premium rate), which would be more attractive for PV installations.

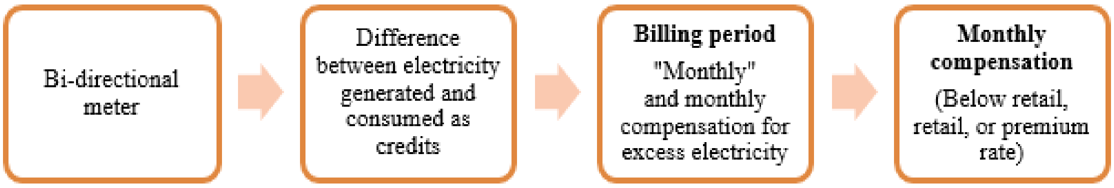

Figure 2.4: Net metering with buy back diagram.

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.1.3 Net metering with rolling credit

The third scheme is net metering with rolling credit. This scheme is the extension of simple net metering by which the banking period extends more than one billing period (typically one year). The compensation in terms of monetary credit will not be applied but this scheme allows prosumers to bank their excess electricity by getting credit (kWh) see in Figure 2.5. If during a billing period there is excess electricity generated, this valued will be used as a credit to reduce the bill in a subsequent billing period. At the end of each billing period in this scheme, the amount of electricity generated that is owed to the prosumer will be decided by taking the difference of the register values from the start to end of the billing period. Credits from the previous billing periods will be applied to this difference. The value of excess electricity will be credited as energetic compensation in kWh.

Since the banking period extends over a number of billing periods, this requires utility to maintain the credit value as well as the register value from the start of the billing period. When the banking period ends, the credit will return back to zero and prosumer will receive no compensation.

Figure 2.5: Net metering with rolling credit diagram.

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.1.4 Net metering with rolling credit and buy back

The last scheme is the combination of rolling credit and buy-back features, which prosumer will receive a monetary credit for any excess electricity generated at the end of banking period usually one year. This scheme works similar to net metering with rolling credit but one more additional way is if there remain credits available on the last billing period within the banking period. The prosumer will gain monetary compensation from the utility, which can be valued in three rates see in the Figure 2.6. The credit will be valued as the same way of net metering with buy back scheme.

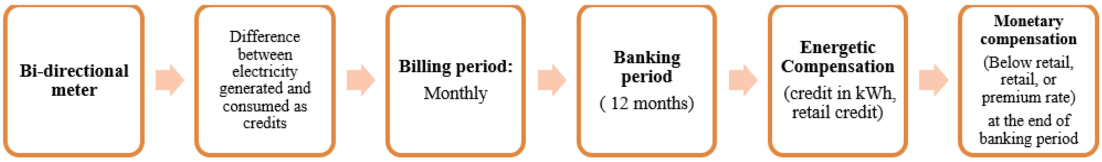

Figure 2.6: Net metering with rolling credit and buy-back

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.2 Net billing schemes

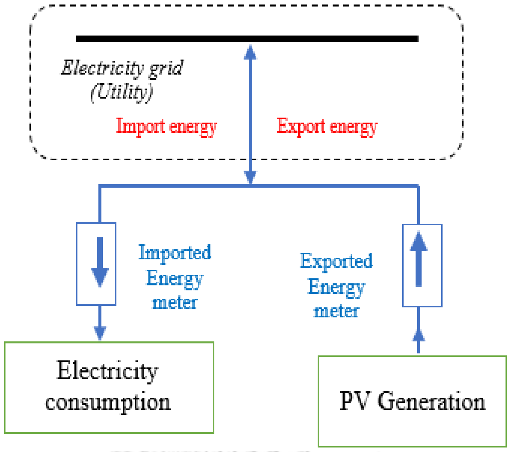

Figure 2.7: Concept of net billing scheme.

Source: Adapted from (Dufo-López et al., 2015; Nikolaidis et al., 2017).

Basically, net billing uses two registers for record the amount of electricity consumed and amount of electricity generated by prosumers within the billing period and hour period. This mechanism allows prosumers to gain their payment from the excess part of electricity as represented in Figure 2.7. Net billing can be categorized into four schemes as following:

2.2.2.1 Net billing with buyback

This scheme allows prosumer to gain compensation for the excess part of electricity in monetary unit at the end of each billing period or hour period. Prosumers pay the electricity that imported from the grid at retail price and gain the payment from the excess part of electricity at a certain rate (below, equal, or above retail rate) as shown in Figure 2.8.

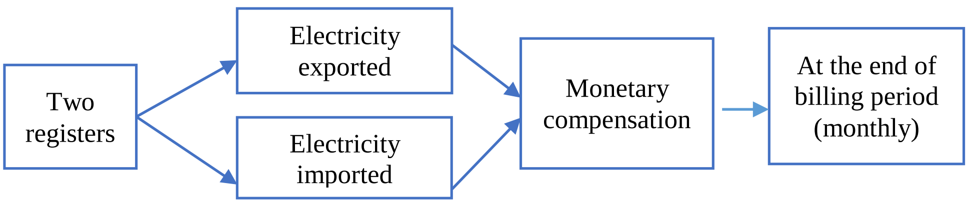

Figure 2.8: Net billing with buyback

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.2.2 Net billing with rolling credit

This scheme allows prosumers can roll their monetary credit throughout a banking period, typically one year. This credit can be used to offset charges in the subsequently billing period. This scheme is functionally same as net metering with rolling credit except this scheme require two registers. Since utility need to know the amount of electricity consumed and amount of electricity generated and combined them to determine the credit the monetary prosumer may obtained as shown in Figure 2.9**.**

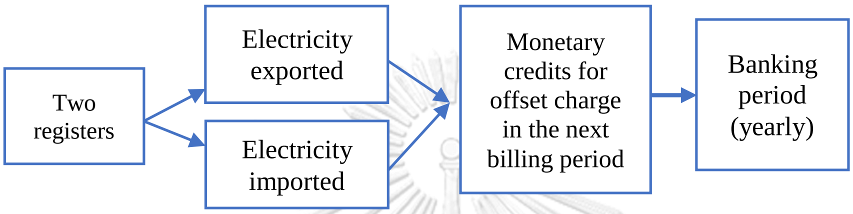

Figure 2.9: Net billing with rolling credit

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

2.2.2.3 Net billing with rolling credit and buyback

This scheme is the combination between rolling credit and buyback features, which allow the excess part of electricity to be banked between billing periods. At the end of banking period, the leftover credits will be bought by the utility at any rate (below, equal, or above retail rate) as shown in **Figure 10**.

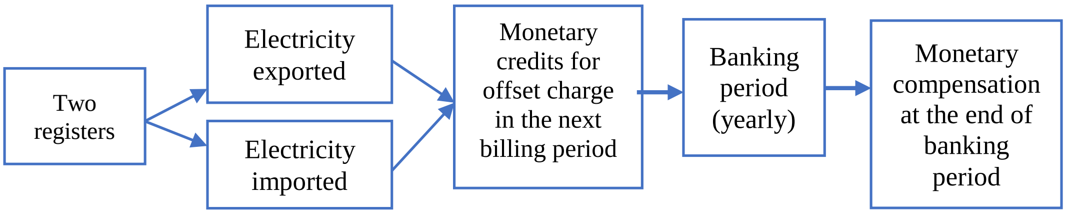

Figure 2.10: Net billing with rolling credit and buyback

Source: Adapted from (Dufo-López et al., 2015; Hughes et al., 2006)

Table 2.2 represented the different criteria of net metering and net billing schemes based on literature review.

Table 2.2: Summary net metering and net billing schemes based on literature review

Type	No. of register	Rolling credit	Buyback rate	Banking period
Simple net metering	1	-		No
Net metering with buyback	1	-	Retail rate	No
Net metering with rolling credit	1	Retail credit	none	No
Net metering with rolling credit and buyback	1	Retail credit	Retail rate	Yes (Typically, one year)
Net billing with buyback	2	-	Flexible rate (below, equal, or above retail rate)	No
Net billing with rolling credit	2	Retail credit	None	Yes
Net billing with rolling credit and buyback	2	Retail credit	Flexible rate (below, equal, or above retail rate)	Yes
Net billing with real-time buyback	2	No	Flexible rate (below, equal, or above retail rate)	No

Source: (Dufo-López et al., 2015; Hughes et al., 2006)

2.3 Literature on self-consumption schemes

2.3.1 Analyses of net metering and net billing schemes

The world's first net metering program was introduced in 1979 in the US state of Massachusetts, and Minnesota was the first state to enact a net metering regulation in 1983. Since then, 13 additional states have enacted net metering regulations, such as California, Connecticut, Idaho, Indiana, and Iowa. There are different terms of net metering that have been used widely in different countries (Y.-H. Wan et al., 1998; Y. Wan, 1996). Net metering itself can be applied in various ways under different objectives, depending on the countries' regulations.

Prior studies have performed comparative assessment of net metering schemes, specifically in the forms of profitability for customers in residential and commercial sectors. A growing number of studies on net metering policy have analyzed the economic impacts of several net metering schemes for broader groups, encompassing not only consumers but also utilities and the society at large.

Dufo-López and Bernal_Agustín (2015) conducted an economic analysis of net metering and net billing schemes for two alternatives of the royal decree drafts proposed by the Spanish National Energy Commission in 2011. The first draft proposed a net metering modality with rolling credit (one year banking period) and the second draft proposed a self-consumption scheme, including a back-up charge. The study compared different net metering schemes and net billing schemes to the base case study (No PV system). The authors concluded that the first draft regulation was a better alternative; it can make the PV systems more profitable. Details of the regulation that will have an impact on the customer include a back-up charge, a service charge and an access charge. In addition, the authors advocated for net metering schemes similar to those applied in the U.S since they have shown to stimulate substantial growth in PV market. The situation faced in this study mirrors the current situation in Thailand in which the initially launched pilot project has been designed for self-consumption only. In my point of view, the economic result of this study could give an overview for policymakers to redesign a net metering scheme that could be beneficial to customers.

Similar to the Brazil case, which first introduced net metering regulation in April 2012 for small-scale power plants, Holdermann et al. (2014) examined the economic viability of PV systems for both residential and commercial sectors using the photovoltaic in the context of net metering introduction (net-metering with rolling credit: allowing compensation for surplus generation into the grid in the form of kWh credit for a banking period of 36 months). The electricity tariffs of the 63 Brazilian distribution networks were utilized as the base case scenarios and the authors use the discounted cash flow method to calculate the economics of PV in 63 distribution networks in Brazil. Despite the presence of the net-metering scheme, none of the PV systems is economically viable for both residential and commercial sectors. The authors suggested that financial options would be required to render the PV systems profitable in both sectors. They also argued that the regulatory framework should be improved for scaling up the deployment of rooftop solar PV systems; otherwise the PV market would not grow substantially.

Under the current circumstance, the number of private households and companies that invest in PV systems are still limited. On the other hand, if the levelized cost of electricity (LCOE) production from rooftop solar systems is less than the electricity tariffs for both residential and commercial sectors, PV system can be more attractive and profitable to invest (Branker et al., 2011).

For the case of Brazilian, in my point of view, is similar to Thailand in regard to the net metering scheme that offers no revenues for the surplus generation that is fed back into the grid; the Brazilian scheme, however, offers credit in kWh for excess electricity for a period of 36 months. Even so, the analyses show a lack of feasibility for all projects. The current pilot project in Thailand may experience a similar outcome of the base cases scenarios in Brazil with low profitability to invest solar rooftop system. Policymakers will face many challenges to design a scheme that can attract people to invest in rooftop PV system; such a scheme may include reward for generation surplus and attractive financial options.

Previous studies assessed the profitability of PV systems under different regulation schemes. Colmenar-Santos et al. (2012) assessed the potential profitability of PV household self-sufficiency system. Researchers concluded that self-sufficiency can be economically profitable if exported electricity is sold at prices below the current FiT for grid-connected PV installation in Spain. This study also found that IRR can be higher than 12% and payback period of less than 10 years can be achievable by increasing remuneration of surplus energy (Colmenar-Santos et al., 2012).

In the case of China, Zhang et al. (2015) examined the current PV policy, which have changes since 2013. The study conducted PV stakeholders' interviews, including DG PV installer, project owners, government officials, and representatives from nongovernmental organization that involves in distributed PV industry. The main questions were related to the cost breakdown of PV projects, the timeline and the main barriers in the process of completion of PV projects. In addition, this study calculated IRR for distributed PV projects on various policy frameworks by creating cash flow for Chinese residential and commercial sectors. Researchers conducted four cases, including 100 % of generation is self-consumed for both residential and commercial sectors, zero generation is self-consumed, and 100% of generation is valued at the local large-scale PV system. The results of IRRs show 14-23% if all the generated electricity is self-consumed, while IRRs falls between 6-7% with zero self-consumption. The result of stakeholders' interview indicated that uncertainty of project returns and the result of difficulty securing project financing under the self-consumption FIT scheme are the main barriers of distributed PV in China. They highlight other barriers to distributed PV in China, including complicated ownership structures and the principal-agent relate to profit sharing (Zhang et al., 2015).

Chiaroni et al. (2014) assessed the profitability of self-consumption PV systems by conducting a survey of 750 companies with systems between 3 kW and 1 MW, using NPV and the discounted payback time (DPBT) as profitability indicators. This study concludes that PV for self-consumption is profitable if DPBT is between 5 and 6 years for residential PV installations, and between 6 and 8 years for large systems (1 MW), and at least 12 years for smaller commercial and industrial installations (Chiaroni et al., 2014).

2.4 International experiences on self-consumption schemes

Self-consumption scheme have been implemented and applied throughout the world. Compensation scheme for self-consumption includes real-time, simple net metering, net metering with rolling credit (no buy-back), net metering with rolling credit and buy-back, Simple Net Billing, Net billing with rolling credit and Net billing with rolling credit and buyback. In the *Flanders* (Belgium) nations the self-consumptions scheme use Net-metering. This scheme is only applicable to system installations within a capacity less than 10 kW. For this scheme there is no direct fiscal compensation for the return electricity to main grid, but the financial equivalent of the return kW is subtracted from the total electricity statement. However, the downside of this scheme is that if the systems installation injected surplus electricity into the main grid beyond it has consumed from the main grid at certain billing period, this surplus amount will not be financially reimbursed (Masson et al., 2016; Poullikkas et al., 2013).

Table 2.3: International experiences of self-consumption scheme worldwide

Compensation schemes	Self-consumed electricity	Rolling credit timeframe	Buyback rate	Banking Period	Meter	Countries	Sources
Real-time	√	Hourly	Wholesale	×	2	Sweden (some utilities)	IEA,PVPS (2016: 27)
	√	Hourly	Wholesale	×	2	Denmark	RES Legal (2017) and Energinet (2017)
Simple Net Metering	√	×	×	Billing period (monthly)	1	Spain (no payment for excess for system<100 kW; above 100 kW can sell in wholesale mkt)	IEA PVPS (2016: 26)
	√	×	×	Billing period (monthly)	1	Thailand's rooftop PV pilot project,	(GIZ, 2017)
	√	×	×	Billing period (monthly)	1	Belgium (in Flanders only and for system<10 kW)	(RES, Legal, 2017)
Net metering with rolling credit (no buy-back)	√	Yearly	Retail	Yearly	1	USA (Columbia, Illinois, Pennsylvania, Louisiana, Arizona, Maryland	(DSIRE, 2017)
	√	Yearly	Retail	Yearly	1	Greece	(RES, Legal, 2017)
Net metering with rolling credit and buy-back	√	Yearly	retail rate	Yearly	1	USA (New York, New Jersey, Nevada ,Columbia)	Originenergy, 2017
Simple Net Billing	√	No	N/A	No	2		
Net billing with rolling credit (no buy-back)	√	Yearly	No	Yes	2	USA (Rhode Island)	(DSIRE, 2017)
Net billing with rolling credit and buyback	√	Yearly	Average wholesale	Yes	2	Italy	(RES, Legal, 2017)

Source: Adapted from ((Dufo-López et al., 2015; Masson et al., 2016)

In the state of Columbia, US, the scheme is credited to prosumers next electricity statement indeterminately at retail rate which include generation, transmission and distribution. This scheme is for systems of 100 kW or less, and at generation rate for greater systems up to 1 MW (March 2, 2017). For California, the net excess generation is credited to prosumers next billing at retail rate. The excess electricity bill credits, however, are subjected to not to be used taxes offset, minimum charges, or other charges which are not energy based. Thus, any remaining billing credit remains when the prosumer terminates service, the credit balance will be granted to the utility (February 2, 2017). In the state of Illinois, the scheme is non-competitive towards customers. The credited to prosumers next cycle bill as a kWh credit is at the retail rate, however, at the end of a 12-month billing cycle any remaining credit is granted to utility (January 25, 2017). For the state of Pennsylvania, the self-consumption scheme suggest excess generation is credited to prosumers next billing at full retail rate and reconciled at every year end at "price-to-compare" (January 23, 2017)

For other state in the US, such as New York, the self-consumption scheme suggests the excess generation is generally credited to customer's next bill at retail rate. At the end of each annual billing cycle, most customers (i.e., residential PV and wind and farm-based wind and biogas systems) will be paid at the utility's avoided-cost rate for any unused NEG. In the Rhode Island, it is credited at avoided cost, rolled over to next bill or will be buy back by utility.

In the case of the State of New Jersey, customer-generator receives month-to-month credit for net excess generation at the full retail rate and is compensated for remaining net excess generation at the avoided cost of wholesale power at the end of an annualized period. On real-time basis, customer-generated excess energy is compensated according to the PJM power pool real-time locational marginal pricing rate, adjusted for losses by the respective zone in the PJM. In Arizona State, the net excess generation is credited to prosumers next billing period at retail price and held for same time of use period. For the State of Nevada, all exported generation is credited at the avoided cost rate. Any credits that exceed the prosumers monthly bill will be carried over to the next billing period. Remaining credits at the end of the year will be paid to the customer. In Idaho, the self-consumption scheme recommends the net energy excess generation is credited to customer's next bill at retail rate for residential and small commercial customers; credited at 85% of non-firm energy rate for all others. Connecticut the self-consumption scheme implied that excess generation is carried over as a kWh credit for one year; Compensated to customer at the avoided cost of wholesale power at the end of the year (March 31). For the State of Montana and State of Maine, it is credited to customer's next bill at retail rate and granted to utility at end of 12-month period

The self-consumption scheme in the Mississippi State suggested the excess generation is sold to the utility at avoided cost plus distributed generation benefits adder (2.5c/kWh) and the energy credit value is carried over indefinitely (July 12, 2016). For the State of Maryland, it is also credited to customer's next bill at retail rate and reconciled annually in April at the commodity energy supply rate (July 12, 2016). Meanwhile, in New Mexico, the self-consumption scheme implies the excess generation is either credited to customer's next bill at avoided cost rate or the excess kWh generated are credited to the account and rolled over indefinitely (equivalent to retail rate) (e.g., available to PNM customers). If customer leaves the utility, unused credits are paid out at the avoided cost rate (DSIRE, 2017).

Comparatively, in Japan, the energy transition from FiT toward self-consumption PV market’s switch from a feed-in tariff (FiT) driven (James, 2014). The Japanese government has confirmed that FiT prices will fall to ¥21 (US$0.18)/kW this year with further drops expected next year, meaning that from then it will be as economical to self-consume onsite generated power as to sell it back to power companies. As an effort to lower the tariff, the government is now confirming the introduction of annual 500 MW tenders, each of the three big utilities are preparing to see the already strong residential market take off further and commercial PV continue to grow (Colthorpe, 2017).

Italy utilized the Net-metering (“Scambio sul Posto”) for system between 20 kW and 200 kW kW**.** Under Scambio sul Posto, prosumers pay utilities for the electricity consumed The Self / local consumption (“Sistemi Efficienti di Utenza: SEU”) consumed electricity produced by systems 3 kWp is exempted from the payment of all variable cost components of the electricity bill. The self- or locally consumed electricity produced by systems between 3 and 20 kW are charged 30€/year. SEU systems can follow to the net metering or to the feed in premium schemes or they can sell their excess electricity to a trader or to the power exchange. The Feed-in-premium (“Ritiro Dedicato”) or tendering system is systems up to 1 MW can choose between selling the electricity that they inject into the grid to the GSE (Gestore Servizi Energetici) agency at the hourly electricity price per market area (Solar Power Europe, 2016).

Denmark net-metering calculated on an hourly basis (§ 3 par. 1 and § 4 par. 1 BEK 999/2016). Calculation of net settlement for all groups that Energinet.dk will obtain a number of kWh electric power utility, which prosumers use to calculate the payment of surplus production (kWh x price supplement). Payment of excess generation will be automatically added to prosumers electricity billing cycle unless stated upon registration. For most settlement groups (group 2,4 and clean production) paid surplus once a month, while the surplus for Group 6 are settled once a year if there is a surplus after the yearly reading. Two different regulations depending on the system size, where, for Type 1: under 100 kW, self-consumption is allowed but the prosumer receives no compensation for the excess PV electricity injected into the grid. Meanwhile, for Type 2: Above 100 kW without limitation, self-consumption is allowed and the excess PV electricity can be sold on the wholesale market directly or through an intermediary. A specific grid tax of 0.5 EUR/MWh has to be compensated together with a 7% tax on the electricity produced. All systems applied for self-consumption above 10 kW are charged with a fee per kWh consumed. It is justified as a "grid backup toll" and is known as Sun tax (Poblocka-Dirakis, 2017).

In the Vietnam, based on policymaker Decision No. 11/2017/QD-TTg on supporting the development of solar power, the new regulation introduces a Feed-in Tariff (FIT) scheme for solar plants and a net metering mechanism for residential PV sector. This regulation come into force in June 1, 2017 and will expire on June 30, 2019. As for net metering, Vietnam's Ministry of Trade and Industry will be in charge of annually issuing the related buying and selling prices for rooftop grid-connected PV systems based on the VND/$ exchange rate (Kenning, 2017).

In Thailand, representing the growth of Thailand's grid-connected solar power capacity, which has been remarkable since 2011 and almost 99% comes from the large-scale solar installations with installed capacities over 1 MW. This growth was incentivized by the adder scheme implemented since 2007. The adder scheme provided incentives to power producers that sell electricity produced by RE at a strong tariff for a specified period of time. However, the adder scheme was discontinued due to the concerns of the impacts to ratepayers and converted to a new Feed in Tariff (FiT) (Tongsopit et al., 2016).

The rooftop FIT scheme assigned a fixed rate for each scale of rooftop PV systems in order to encourage customers to install solar PV systems to sell power to the grid. FiT is financed through the levy on the electricity bills (FT rate) for all electricity consumers and is valid for 25 years. The rooftop FiT program launched between 2013 and 2015 sets a quota of 200 MW of power purchase agreement (PPA) available, allocating 100 MW to commercial rooftops (10-1000 kW) and another 100 MW to residential (0-10 kW) rooftop solar systems. The result showed that the quota for commercial rooftop systems was reached quickly, while the residential quota was slowly subscribed. The FiT policy was discontinued in 2015.

Figure 2.11: Thailand rooftop solar PV policy development (GIZ, 2017).

Despite the discontinuity of the FiT support scheme, another support scheme for rooftop PV systems was proposed to replace the FiT. In January 2015, the Thai cabinet announced the net metering scheme as the pilot project for the purpose of self-consumption. Later, in March 2016, National Energy Policy Council (NEPC) proposed a pilot project for the purpose of self-consumption. This pilot project aimed to support rooftop solar PV systems for on-site consumption only and any excess electricity injected back into the grid would not be compensated. The objective of this rooftop solar PV pilot project was first to study, monitor and then evaluate the impact of self-consumption on the utilities, the distribution systems, and the investors. Within a total 100 MW quota, 20 MW was allocated to residential roofs, which was divided equally into 10 MW (≤ 10 kWp) in Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) areas and the remaining 80 MW was allocated to commercial roofs, which MEA and PEA each allow for 40 MW (10 kWp to 1 MWp) (DEDE, 2016). The application process was already closed for submission and all participants must install their rooftop solar PV by January 31, 2017. The current status of the uptake of Thailand rooftop solar PV pilot project was low, with approximately 38 MW approved out of the quota of 100 MW (GIZ, 2017).

2.5 Research contribution

The previous studies in section 2.3 on self-consumption schemes suggested the research methodology on economic feasibility for solar PV installation that being implementation in some countries. In section 2.4, an international experience presented varies self-consumption schemes in details. This section discussed compensation methods, timeframe of rolling credit and the value of excess electricity in different regions around the world. In summary, most of prior studies on the self-consumption schemes of rooftop solar PV policy have focused on the analysis of self-consumption schemes including net metering and net billing in term of economic feasibility of the investment. This research contributed further to existing body of knowledge by assessing the economic feasibility of self-consumption schemes for residential and commercial sectors, analyzing the technical factors that support or block the implementation in each type of self-consumption schemes, and investigating stakeholders' perspectives on detail design options of self-consumption based on literature review. Finally, this research synthesized the findings from these three areas in order to recommend the most sustainable supporting scheme for rooftop solar PV development for residential and commercial sectors in Thailand.

CHAPTER 3
METHODOLOGY

3.1 Conceptual framework and research outline

The conceptual framework in this research consisted of three main components, economic feasibility analysis, technical analysis, and stakeholders' perspectives analysis as shown in Figure 3.1. All three components were analyzed together in order to assess the economic feasibility and barriers associated with each types of self-consumption schemes, including net metering and net billing schemes. The details of each component were described in the next sections.

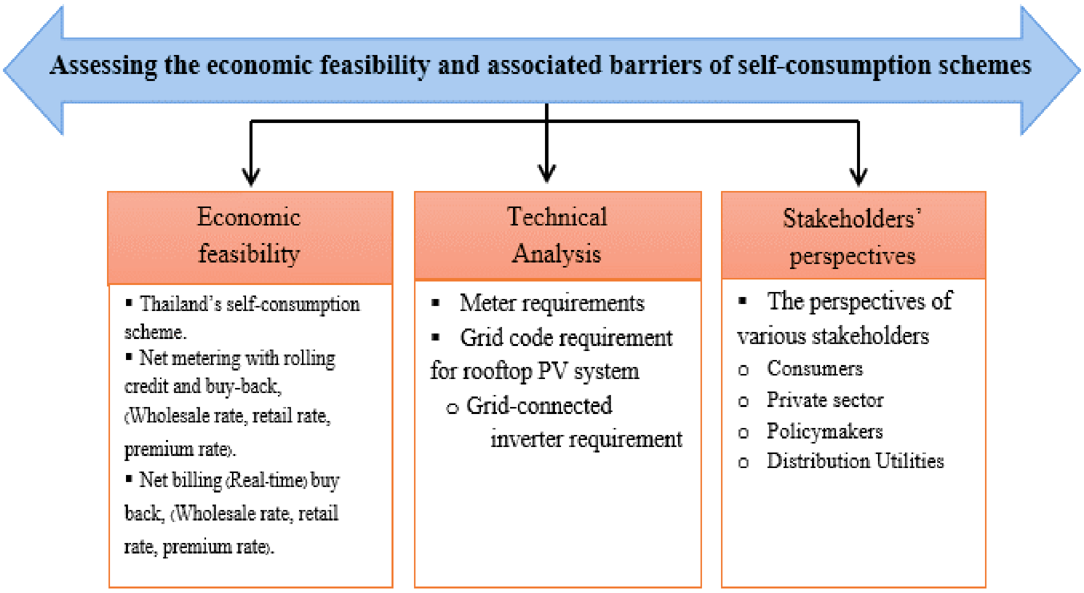

Figure 3.1: The conceptual framework to assess the sustainability of self-consumption schemes.

3.2 Economic analysis framework and data collection

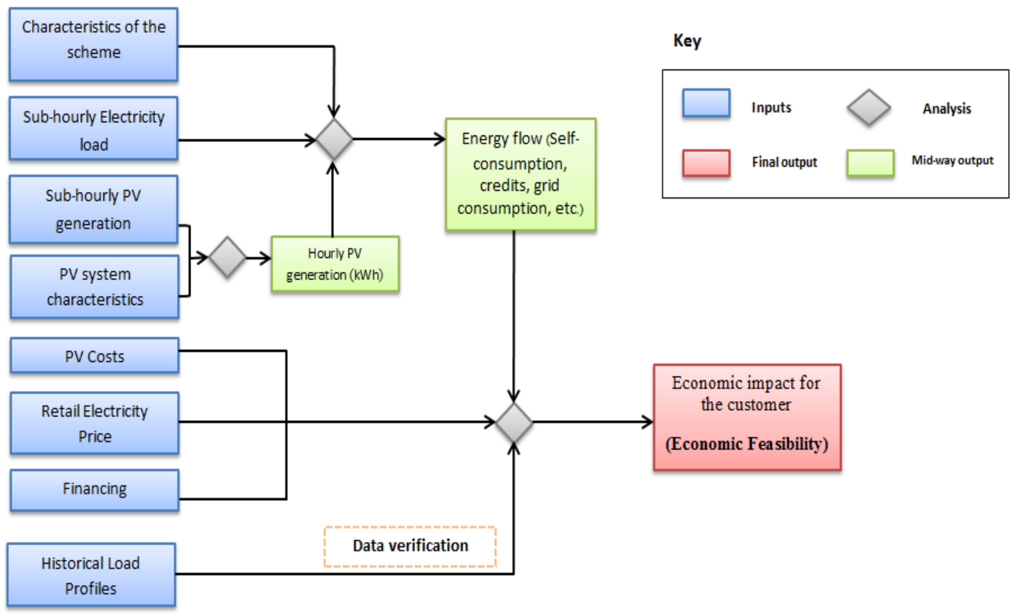

Figure 3.2: Research methodology framework of economic analysis

Source: Adapted from (Masson et al., 2016)

The framework in Figure 3.2 represented the relationship of the parameters that is used to assess the economic feasibility of a PV investment for prosumer. In this framework, all parameter were utilized except for sub-hourly PV generation was not concern the research objectives.

Economic analysis was carried out by calculating Net Present Value (NPV), Internal Rate of Returns (IRRs) and Payback Period (PB) of selected self-consumption schemes, including Thailand's self-consumption scheme, net metering with rolling credit and buy back, and net billing with real-time buyback. These three measures were used in order to assess the economic feasibility of solar PV investment of 5 kW and 100 kW of rooftop PV system for residential and commercial scaled projects, respectively. This research used payback period as a main criteria to assess the feasibility of solar PV investment for consumer.

For this research, net present value (NPV) was calculated according to Eq. 1. Net present value is a measure of a project's economic feasibility that includes both revenue (cash inflow) and cost (cash outflow). In this analysis, the revenue was the saving from the electricity generated from the rooftop PV installation and the compensation from the excess part of electricity. The cost, or cash outflows was associated with an investment of the project.

$$NPV = \sum_{n=0}^{N} \frac{\mathrm{C_n}}{(1 + d_{nominal})^{n}}$$

Equation 3.1 Net present value
Source: System Advisor Model, 2017

Where C_n is the after-tax cash flow in Year,
n is the analysis period in years, n = 0 is the year of the first investment
$d_{nominal}$ is the nominal discount rate.

For the NPV assessments, the criteria for determining whether the project is economically viable follow:
NPV > 0, investment is economically viable, investor gain a profit
NPV = 0, investment is economically viable, investor gain no net benefit, investor can only recover the initial investment.
NPV <0, investment will not be economically viable.
Net present value is calculated as the present value of the after tax cash flow discounted to year one using the nominal discount rate.
NPV is the most accepted standard method used in financial assessment for long-term projects. However, the value can vary, depending on the discount rate.

The internal rate of return (IRR) showed the return that the cash flows received from an investment. The IRR is the nominal discount rate that corresponds to a net present value. If IRR is 12%, it means that the solar energy investment is projected to generate a 12% return through the life of the solar system. The IRR was calculated according to Equation 2.

$$\text{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+\text{IRR})^n} = 0$$

Equation 3.2: Internal rate of return
Source: System Advisor Model, 2017

Where C_n is the after-tax cash flow.
n is the analysis period in years, n = 0 is the year of the first investment
The higher IRR of the project, the more feasible investment is.

The last indicator was the payback period (PB). The payback period of a rooftop PV system can be defined as the length of the time. It takes for the initial investment to fully be recovered by the savings it makes. Investors in general tend to prefer short payback periods. In summary, these three indicators together could measure the economic feasibility of the selected self-consumption schemes of rooftop PV installation.

In order to calculate the NPV, IRR, and payback period, this study simulated a set of data using System Advisor Model (SAM), which was developed by the National Renewable Energy Lab (NREL) in the United States (U.S). SAM is a performance and financial model designed to predict the cost of energy for grid-connected power projects based on various parameters, including financial parameters, system design, operating cost, electricity tariffs, specify as inputs into the model (Blair et al., 2014). A number of inputs were required to run the software, including characteristics of selected scheme, technical and financial parameters, and cost breakdown and electricity tariff rate. These inputs were discussed in the sections below.

Description of model inputs and assumptions were as follows:

3.2.1 **Characteristic of selected schemes**

The selections of the schemes for modeling were based on literature review and result of stakeholders' perspectives analysis, which was discussed in Chapter 6. There were 3 main schemes to be modeled as following:

3.2.1.1 Scheme 1: Self-consumption scheme (Thailand's Rooftop PV Pilot Project)

The first scheme was based on Thailand's Rooftop Solar PV pilot project, which encourage customers to install their PV system to generate electricity for self-consumption onsite first. Excess part of electricity that was injected back into the grid would gain no compensation. The Pilot Project allocated a quota of 100 MW to be distributed equally for MEA and PEA service areas. The quota allocation for residential and commercial sector was shown in Table 3.1. As of October 2017, the pilot project was completed with low uptake of approximately 38 MW approved out of the 100 MW target. Currently, the government is considering a compensation scheme for excess generation for the next phase (GIZ, 2017).

Table 3.1: Quota of PV rooftop self-consumption scheme (in MW)

Areas	Residential* rooftop	Commercial** rooftop	Total
MEA	10	40	50
PEA	10	40	50
Total	**20**	**80**	**100**

* Residential electricity users (Type 1), system size (0- 10 kW)
** Commercial electricity users (Type 2- 6), system size (> 10 kW-1MW)
Source: (DEDE, 2016).

3.2.1.2 Scheme 2: Net metering wit rolling credit and buyback

Scheme 2 was a combination of a rolling credit and buyback features. This scheme allowed prosumers to gain the compensation from the excess part of the electricity as credits at the retail rate. Prosumers can bank their excess part of the electricity. At the end of the first the billing period, if there any excess electricity, it could be kept as credit and rolled over to the next month to offset the next month's consumption. If excess credits are left at the end of the second month, the credit gets rolled over to the third month, and so on until the end of banking period (typically one year, depending on the policy). Thus, prosumer can reduce their own electricity bill; in addition, if there are leftover credits at the end of banking period, the prosumers can gain payment at wholesale rate, retail rate, or premium rate.

3.2.1.3 Scheme 3: Net billing with real-time buy back (no rolling credit)

This scheme values the excess part of electricity at a rate that is different from the retail rate. Net billing basically uses two registers for record the amount of electricity consumed and amount of electricity generated by prosumers within the billing period and hourly period. This scheme allows prosumers to gain their payment from the excess part of electricity (Dufo-López & Bernal-Agustín, 2015).For each hour; any excess part of electricity that is being injected back to the grid is valued at a certain buyback rate. Net billing requires the measurement of two different flows of energy because they are treated at different rates. The values associated with these two flows are then netted to calculate the total of electricity bill at the end of billing period. The net value can be kept as credits that roll into the next billing period to offset next month's bill. Or it can be settled at the end of the billing period. This study chose net billing with real-time buyback (no rolling credit), this scheme involves real-time or hourly valuation of excess generation. For each hour that the PV system generates electricity more than the load, that excess electricity is fed back to the grid at the buyback rate for that hour. Conversely, if PV system generates electricity less than the load, prosumers buy the electricity at the rate of that hour. The buyback rate can be below retail, equal to retail, or above retail rate. At the end of monthly electricity billing, prosumer will gain compensation in combined monetary valuation from all hours in the month.

3.2.2 Technical parameters and Financial parameters

3.2.2.1 Technical parameters

This research designed the PV system based on appropriate technical characteristics of rooftop PV system in Thailand. For system configuration, the researcher modified the residential load profile by increasing its peak to 5 kW and PV system has to serve 100% of peak load. Hence, a 5 kW PV system was considered where it is applicable for residential block rate and TOU rate. The residential system modeled here was connected to low voltage line (230/400). For medium-general business, such as commercial buildings, the considered load profile was 100 kW. The commercial system was connected to higher voltage level (>12 kV).

The residential PV system was composed of 20 modules of Jinko JKM-260P-60B. The system was grid-tied through SMA SB 5000TL inverter, in two strings of modules apiece. For the system lifetime degradation, the median system lifetime degradation rate was 0.5% per year, which was based on an average degradation rate of mono- and multi-crystalline modules survey from systems all over the world (Jordan et al., 2013)The panels were oriented to face south (azimuth angle at 180 degree) with a tilt degree of 13.7 degrees, which are the direction and tilt angle that maximize sunlight exposure in Bangkok location (Punyachai et al., 2014). Other technical parameters are listed in Table 3.2.

Table 3.2: Technical parameters

Category	Unit	Residential	Commercial	Explanations & Sources
Weather data	N/A	Bangkok	Bangkok	
System size	kW	5	100	Determined by the researcher
Module	N/A	Jinko JKM-260P-60B	JA solar JAP6 72/300/ 3BB	Determined by the researcher to match the system sizing
Module type	N/A	Polycrystalline Silicon	Polycrystalline	Determined by the researcher based on market survey
Inverter	N/A	SMA Sunny Boy 5000TL	SMA TRIPOWER 2000TL	Determined by the researcher to match the system sizing
Inverter efficiency	%	96	97.7	Determined by SAM based on selected inverter
Module nominal peak power	Wdc	260.307	300.018	Determined by SAM based on selected module
Module per string	N/A	10	17	Determined by the researcher using SAM
String in parallel	N/A	2	22	Determined by the researcher using SAM
Number of inverter	N/A	1	5	Determined by the researcher to match the system size.

Category	Unit	Residential	Commercial	Explanations & Sources
DC to AC ratio	N/A	1.14	1.12	Determined by SAM based on system design
Tilt	Degrees	13.7	13.7	Local latitude
Azimuth	Degrees	180	180	South-facing
System lifetime degradation	Year	0.5%	0.5%	(Jordan et al., 2013)
Capacity factor	%	16	16.4	SAM result based on system sizing
Performance ratio	%	0.76	0.78	SAM result based on system sizing

Capacity factor and performance ratios for both residential and commercial sectors were calculated based on simulation results in SAM. The results for the capacity factor of the residential scale and commercial scale systems were 16% and 16.4%, respectively. Meanwhile the results of performance ratio were 76% and 78%, respectively. Performance ratio was normally between 75-90% for PV systems due to losses caused by inverter, wiring, and module soiling (Rodrigues et al., 2015)

The commercial PV system design consisted of 34 modules of JA solar JAP6 72/300/ 3BB Polycrystalline. The system was grid-tied through SMA Tripower 20000TL in two strings of modules apiece. The system design was determined by the researcher to match the load and these PV modules and inverter type are available in market. The rest of the technical parameters were the same as the residential PV system as shown in Table 3.2.

3.2.2.2 Financial parameters

Table 3.3: Financial parameters for the residential and commercial-scale systems

Financial parameters	Residential	Commercial	Explanations & Sources
Loan type	Self-financed	Self-financed	Determined by the researcher
Debt fraction	0	0	Determined by the researcher
Analysis period	25 years	25 years	Determined by the warranty of solar module

Financial parameters	Residential	Commercial	Explanations & Sources
Inflation rate	1.2	1.2	BOT, 2017
Real discount rate	3.28*	6.62**	BOT*, 2017, SET**,2016
Insurance rate	0.04	0.12	Based on EPC price survey
Electricity escalation	3.5%	3.5%	Tongsopit et al., 2017

Table 3.3 showed the financial parameters for both residential and commercial sectors, which based on self-financed PV systems. The project period was expected to have a 25-years life span to match with the warranty period. Inflation rate was at 1.2% based on the Bank of Thailand and real discount rate of residential sector was at 3.28%, based on government bond yield over 20 years (Bank of Thailand, 2017). For commercial real discount rate was at 6.62 % based on average 5-year return of investment in energy sector. The insurance cost was at 1% of residential 5 kW PV system and 3 % of commercial 100 kW PV system based on EPC contractor survey. Electricity growth rate was at 3.5%.

3.2.3 Cost breakdown for installing 5 and 100 kW PV system

Table 3.4: Cost breakdown for installing 5 kW and 100 kW PV system in Thailand during 2017(THB/W)

Fixed cost					
System costs	Residential scale		Commercial scale		Sources
Module costs	19.8	THB/W	17.28	THB/W	Market price survey (May-June, 2017)
Inverter costs	13	THB/W	11.6	THB/W	Market price survey (May-June, 2017)
Labor installation costs	11.75	THB/W	10	THB/W	Market price survey (May-June, 2017)

Permitting cost	2.75	THB/W	2.4	THB/W	Market price survey (May-June, 2017)
Engineering and developer overhead	7.7	THB/W	6.72	THB/W	Market price survey (May-June, 2017)
Total costs	**55.82**	**THB/W**	**48.48**	**THB/W**	

Source: Based on price survey of 10 EPC contractors (May-June, 2017).

Variable cost					
	Residential scale		Commercial scale		Sources
Operation and Maintenance cost	0.5	% of total costs per year	1	% of total costs per year	Determined by researcher
Grid Metering fee	-	-	100,000	THB	(DEDE, 2016)

The system cost for this research based on a market price survey from 10 EPC contractors based in Bangkok between May to June, 2017. The investment cost of residential PV installation (excluding tax 7%) was ranged between 49-70 baht/watt. Researcher excluded 70 baht/watt, which was considered as an outlier. Then, the system cost was calculated from the median of 9 EPC contractors. The average price of PV installation used in this model was at 55 THB/watt for a 5 kW PV system. For the investment cost of a 100 kW PV system, the researcher also did a price survey from 10 EPC contractors, showing the cost of installation ranging between 38-60 baht/watt and the average price was at 48 baht/watt. These prices of both residential and commercial PV installations included module cost, inverter cost, engineering and developer overhead, permitting cost and labor installation cost as given in Table 3.4. Even though the investment cost of PV installation may vary from system to system due to variations system size and other factors such as location and type of PV module and inverter, this study calculated the price per kilowatt and took an average for each level of sizing.

The operation and maintenance cost (O&M) was applied yearly throughout the lifetime of the PV system. The O&M cost was estimated between 1%-3% of the initial cost of investment per year (Rodrigues and Chen, 2016). In this research, O&M cost of 5 kW and 100 kW PV system for both residential and commercial sectors were considered to be 0.5 % of the total installation cost and 1% of total installation cost respectively. There was an additional fee of meter and meter monitoring for commercial PV systems, that are connected to higher voltage level (> 12 kV). They were required to pay 100,000 baht (not include vat 7%) for these costs. Thus, this fee was included in the system cost for the commercial PV installation. The inverter was replaced in year 11 and year 22. This assumption was based on a typical inverter warranty of 10 years from EPC contractors.

3.2.4 Electricity tariff rate

In this research, three specific electricity tariffs from eight electricity tariff groups were selected as given in Appendix A. The selected tariff groups were residential block rate (type 1.2), residential TOU rate (type 1.3), and medium general service (12-24 kV: type 3.1.2). The justification of tariff rates was based on PV system sizing in each group in order to match with 5 kW residential sizing and 100 kW commercial sizing. Thus, the selection and implementation of these three electricity tariff groups would be chosen for the economic feasibility analysis based on different selected schemes.

3.2.4.1 Residential Block rate

This tariff represented normal tariffs of electricity user type 1.2 and applicable to household and other dwelling places, temples and other religion places of worship, including its compound, through a single Watt-hour meter. This electricity rate included Ft[1] rate -0.2477 Baht/kWh[2], as given in the Table 3.5.

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[1] Ft is fuel adjustment cost at given time variable tariff that derived from the Automatic Tariff Adjustment Mechanism Formula. Ft formula included fuel cost and purchasing power. Ft is monitored by The Energy Regulatory Commission revised every four months.

[2] as of May-August 2017

Table 3.5: Residential Block rate

Tariffs	Residential Block rate	Unit
1-150 unit	3.0007	Baht/kWh
151-400 unit	3.9741	Baht/kWh
Over 400 unit	4.174	Baht/kWh
Fixed charge	38.22	Baht/month
Ft	-0.2477	Baht/kWh

Source: (MEA, 2017a)

3.2.4.2 Residential Time of use (TOU) rate

This tariff represented normal tariffs of electricity user type 1.3 and applicable to household and other dwelling places, temples and other religion places of worship, including its compound, through a single Watt-hour meter. This electricity rate included the Ft rate, (-0.2477) Baht/kWh, as given in Table 3.6

Table 3.6: Residential TOU rate

Tariffs	Residential TOU/ baht	Unit
on-peak*	5.5505	Baht/unit
off-peak*	2.3892	Baht/unit
Fixed charge	38.22	Baht/month
Ft	-0.2477	Baht/kWh

* On peak: Monday – Friday from 09.00 AM to 10.00 PM

* Off peak Monday – Friday from 10.00 PM to 09.00 AM
Saturday – Sunday , National Labor Day and normal public holiday

Source: (MEA, 2017a)

3.2.4.3 Commercial TOU rate

This tariff represented medium general service type 3.1.2 with voltage level 12-24 kV that applicable to a business, industrial, government institutions and state enterprise. This electricity rate included the Ft rate (- 0.2477) baht/kWh[3], as given in Table 3.7.

Table 3.7: Commercial TOU rate

Tariffs	Commercial TOU/ baht	Unit
on-peak	3.962	Baht/kWh
off-peak	2.3818	Baht/kWh
Fixed charge	312.24	Baht/kWh
Demand charge	132.93	Baht/month
Ft	-0.2477	Baht/kWh

* On peak: Monday – Friday from 09.00 AM to 10.00 PM
* Off peak Monday – Friday from 10.00 PM to 09.00 AM
  Saturday – Sunday , National Labor Day and normal public holiday

Source: (MEA, 2017a)

3.2.5 **Electricity buyback rates**

According to electricity buyback rate for the selected schemes to be modeled, namely net metering with buyback and rolling credit; and net billing with real-time buyback, the buyback rate were classified into three rates, wholesale, retail, and premium (above retail) rates. The buyback rates were drawn from the report on rooftop PV pilot project evaluation (Tongsopit et al., 2017) as shown below:

3.2.5.1 Buyback Rates for Customer Group “Residential block rate”

Table 3.8 shows three buyback rates in each scheme as following:

(1). Self-consumption scheme: no buy back rate, which is zero THB.

[3] as of May-August 2017

(2). Net metering with rolling credit and buyback scheme: In this scheme, excess generation in one billing period is rolled into the next billing period to offset electricity use. At the end of banking period, remaining credits will be purchased at the rates below:

- Average wholesale rate was calculated based on wholesale rate at 11-33 kV on-peak (4.2243 THB/kWh) and off-peak (2.3567 THB/kWh) rates, Ft and transmission cost were included.
- Average retail rate was calculated from retail rate from 3 block residential rates (1-150, 150-400, over 400 kWh), Ft included.
- Premium retail rate was calculated based on additional 10% on top of average retail block rate from 3 blocks, Ft included.

(3). Net billing scheme with real-time buyback (no rolling credit): This scheme involves real-time or hourly valuation of excess generation. For each hour that the PV system generates electricity more than the load, that excess electricity is fed back to the grid at the buyback rate for that hour. Conversely, if PV system generates electricity less than the load, prosumers buy the electricity at the rate of that hour. At the end of monthly electricity billing, prosumer will gain compensation in combined monetary valuation from all hours in the month.

- Average wholesale rate was calculated based on wholesale rate at 11-33 kV on-peak (4.2243 THB/kWh) and off-peak (2.3567 THB/kWh) rates, Ft and transmission cost included.
- Average retail rate was calculated from retail rate from 3 block residential rates residential (1-150, 150-400, over 400 kWh), Ft included.
- Premium retail rate was calculated based on additional 10% surplus of average retail block rate from 3 blocks, Ft included.

(4). Ft rate is -0.2477 baht/kWh for the months of May to August 2017

Table 3.8: Residential Buyback rate (Block rate)

Residential block rate (Buy-back rate)	Wholesale rate (11-33 kV)	Average retail rate	10% above retail rate
Scheme 1 Thailand's self-consumption scheme	0		
Scheme 2: Net metering with rolling credit and buyback	3.0428 Average wholesale rate	3.716 Average retail rate	4.087 1.10 * average retail rate
Scheme 3: Net billing with real-time buy-back	3.0428 Average wholesale rate	3.716 Average retail rate	4.087 1.10 * average retail rate

3.2.5.2 Residential TOU rate

For the residential TOU customer class, there were 3 different buyback rates in each scheme as given in Table 3.9 as following:

Table 3.9: Residential TOU buyback rate

Residential TOU rate (Buy-back rate)	Wholesale rate	Average retail rate	10% above retail rate
Scheme 1: Thailand's Self-consumption scheme	0		
Scheme 2: Net metering with rolling credit and buyback	3.0428 Average wholesale rate	3.969 Average retail rate	4.365 1.10* average retail rate
Scheme 3: Net billing with real-time buy-back	On peak = 3.89 Off peak = 2.02	On peak = 5.55 Off peak = 2.38	On peak = 5.73 Off peak = 2.43

(1). Thailand's Self-consumption scheme

- Self-consumption scheme: no buy back rate.

(2).Net metering with rolling credit and buyback scheme. In this scheme, excess generation in one billing period is rolled into the next billing period to offset electricity used. At the end of banking period, if remaining credits will be purchased at the rates below:

- Average wholesale rate was calculated based on wholesale rate at 11-33 kV on-peak (4.2243 THB/kWh) and off-peak (2.3567 THB/kWh rates, Ft and transmission cost included.
- Average retail buyback rate was calculated from retail TOU rate on peak and off peak, Ft included.
- Premium retail rate was calculated based on an additional 10% on top of average retail TOU rate, Ft included.

(3). Net billing scheme with real-time buyback. In this scheme involves real-time or hourly valuation of excess generation. For each hour that the PV system generates electricity more than the load, that excess electricity is fed back to the grid at the buyback rate for that hour. Conversely, if PV system generates electricity less than the load, prosumers buy the electricity at the rate of that hour. At the end of monthly electricity billing, prosumer will gain compensation in combined monetary valuation from all hours in the month.

- Average wholesale rate was calculated based on wholesale rate at 11-33 kV on-peak (4.2243 THB/kWh) and off-peak (2.3567 THB/kWh, Ft and transmission cost included.
- Retail buyback rates were residential retail TOU rates for on-peak and off-peak hours (Ft included).
- Premium retail rate was calculated based on additional 10% on top of retail TOU rates (peak and off-peak), Ft included.

(4). Ft rate is -0.2477 baht/kWh[4]

3.2.5.3 Commercial TOU rates

The TOU buyback rate is consists of three buyback rates as demonstrated in Table 3.10.

(1). Self-consumption scheme:

- Self-consumption scheme: no buy back rate.

(2). Net metering with rolling credit and buyback scheme. In this scheme, excess generation in one billing period is rolled into the next billing period to offset electricity

[4] As of May – August, 2017

used. At the end of banking period, if remaining credits will be purchased at the rates below:

- Average buyback rate was calculated from wholesale TOU rate at 230 kV from on-peak (3.3922 THB/kWh) and off-peak (2.3316 THB/kWh) rates and Ft and transmission cost included.
- Average retail buyback rate was calculated from retail TOU rate of on peak and off peak, Ft included.
- Premium rate was calculated by added 10% of Average retail TOU rate (Ft included).

(3). Net billing scheme with real-time buyback. This scheme involves real-time or hourly valuation of excess generation. For each hour that the PV system generates electricity more than the load, that excess electricity is fed back to the grid at the buyback rate for that hour. Conversely, if PV system generates electricity less than the load, prosumers buy the electricity at the rate of that hour. At the end of monthly electricity billing, prosumer will gain compensation in combined monetary valuation from all hours in the month.

- Wholesale buyback rate was wholesale TOU tariff at 230 kV on-peak (3.3922 THB/kWh) and off-peak (2.3316 THB/kWh) rates and Ft and transmission cost included.
- Retail buyback rate was the same commercial retail TOU rate (Ft included).
- Premium retail rate was calculated based on additional 10% surplus of commercial retail TOU rate, Ft included.

(4). Ft rate is -0.2477 baht/kWh[5].

[5] as of May-August 2017

Table 3.10: Commercial TOU buyback rate

Commercial TOU rate (Buy-back rate)	Wholesale rate (230 kV)	Average retail rate	10% above retail rate
Scheme 1: Thailand's Self-consumption scheme	0		
Scheme 2: Net metering with rolling credit and buyback	2.86 Average wholesale rate	3.17 Average retail rate	3.34 1.10*Average retail rate
Scheme 3: Net billing with real-time buy-back	On peak = 3.3922 Off peak = 2.3316	On peak = 3.9612 Off peak = 2.3818	On peak = 4.14 Off peak = 2.5

3.2.6 Historical load profiles

Historical load profile data in this research were classified into two representative loads, residential and commercial load profile. Both load profiles were collected from MEA annual load study for the year 2015. Electricity user type 1 was represented as residential load. In this research, the residential load profile was modified to increase its peak load to 5 kW. Meanwhile, the commercial sector's load profile was modified to increase the peak load to 100 kW, which was used to represent the medium general service (electricity user type 3) class. Basically, load profile data were made of power consumption in 15 minute intervals for each day, which classified by electricity tariff rate and monthly electricity use. Researcher aggregated consumption data into 1 hour interval for 8760 hours (1 year) as input to the economic feasibility study.

3.3 Technical analysis framework and data collection

This section assesses technical factors that support or obstruct in each types of self-consumption schemes. The technical factors were classified into two main parts: meter requirement and grid code requirements. Grid code requirements also included rules on interconnection level, voltage regulation, additional protection devices and inverter types. This analysis employed a desk study and interviews with the key experts in order to assess remaining technical barriers occurs in grid code requirement.

3.3.1 Desk study

The desk study in this research involved collecting secondary data by reviewing existing grid codes, governmental reports, and literature review to gain the broad understanding of metering requirement and grid code requirement. Desk study in this research helped to establish a preliminary understanding of technical issues that relate to meter and grid code requirement of rooftop solar installation and then synthesize these two technical issues in order to seek support and barrier factors in each type of self-consumption schemes.

3.3.2 Interview with key experts

This research conducted face-to-face interview with electrical engineering experts in order to gain information as follows:

- Understanding the technical terminology related to grid code of PV installation
- Issues and limitations related to metering requirement and current grid code of PV installation requirement.
- In-depth discussion on information related to technical impacts of reverse power flow due to current self-consumption pilot scheme.
- Possible solution recommendations in order to reduce the technical impacts from PV installation.

Interviewing with the key person provided an opportunity to establish rapport and clarify questions or issues.

3.4 Stakeholders' perspectives analysis framework and data collection

3.4.1 Stakeholder groups

This method of analysis was mainly designed to investigate the perspectives of various stakeholders, including consumers, private companies, policymakers, and distribution utilities on the detailed design options for self-consumption schemes to support rooftop solar PV system installations in Thailand. In order to design the support scheme for the future, researcher began with selecting the support schemes based on literature reviews, which indicated to more adopted schemes of net metering with buyback and net billing with real-time buyback. This framework method employed both qualitative and quantitative methodology. Whereby, firstly it informed the stakeholder groups on the key design elements of PV self-consumption schemes and then, sought their opinions through focus group discussion and questionnaires in order to verify and enhance the findings. The result of focus group discussion and questionnaire survey were used to compare the advantages (pros) and disadvantages (cons) of each self-consumption schemes.

3.4.2 Questionnaire design

Questionnaire survey was a research instrument, consisting of a set of questions (items) intended to capture responses from respondents in a standardized manner (Bhattacherjee, 2012). The questionnaire was designed to quantitatively investigate the perspectives from each stakeholder on each selected scheme option, as attached in the Appendix B. The questionnaire survey of this research was part of Thailand's rooftop PV pilot project evaluation, which specifically focused on the future design supporting scheme for rooftop solar PV system in Thailand based on the need of each stakeholder. The questionnaire was classified it into two main sections.

1. In the first section, respondents were asked to specify their personal information such as age, job, position, and organization.
2. The second section included a list of supporting schemes for solar PV self-consumption. The questionnaire was designed to ask whether the self-consumed electricity and excess generation should be compensated or not. For self-consumed electricity, respondents were asked to select whether it should be compensated for or not, and if compensated, at which rate the compensation should the compensation be. For excess generation, the respondents were asked whether the excess part of the electricity should be compensated for or not. In the case that excess generation should be compensated, the respondents were asked at which rate the compensation should be. In addition, the respondents were asked about the timeframe over which the compensation should occur – whether the compensation should occur in real-time or excess part of electricity was collected as credit to billing period. After that, the respondents were asked to select the rate of

compensation value, which consisted of three rates: below, equal, and above retail rate. Additionally, there were additional questions such as cap for compensation per year and how long the banking period for collecting credits should be.

3.4.3 Focus group discussion

Focus group is the type of research methodology that invites stakeholders to participate in a small group discussion session (typically 6 to 10 people) at a time and at one location. The discussion is moderated and led by a facilitator, who sets the agenda and poses an initial set of questions for participants in order to elicit ideas from all participants. Another role of the facilitator is to build the holistic understanding of the problem statement based on comment and experiences of participants (Bhattacherjee, 2012)

This research drew from the results of the focus groups organized by the research team between September and December 2016. The stakeholders in this research included government officials, policymakers, distribution utilities representatives, regulators, and other fellow researchers in order to ground their views within the domain of supporting rooftop PV policy in residential and commercial scales. Then, researcher designed a questionnaire that took into consideration layman's understanding and avoided too technical questions that might confuse the respondents. Before the questionnaire was answered, the stakeholder's groups were informed on the details of various supporting schemes in order to ground their understanding before they started to answer the questionnaire. The group of stakeholders included:

(i) *Consumers*: were the participants of Thailand's Rooftop Solar PV Pilot Project.

(ii) *Private companies*: included solar EPC contractors, Suppliers, Developers, Consultants, and representatives from the Federal of Thai Industries, all of which have been involved in solar rooftop projects.

(iii) *Policymakers*: included government officials at executive and non-executive levels from the Bureau of Solar Energy Development of Department of Alternative Energy Development and Efficiency, Ministry of Energy, Ministry of Finance, and the Energy Regulatory Commission,

(iv) *Utilities*: there are two distribution electricity utilities in Thailand, namely MEA, which is responsible for providing service and electricity power in Bangkok, Nonthaburi and Samut Prakan and PEA, which is responsible for electricity distribution in 73 provinces. Most of these utility representatives are from Power System Planning Department, Power Economics Department, Business Development Planning, Research and Development Department.

(v)Others: include academic researchers, financial analysts, research consultants

This quantitative analysis for investigating the stakeholders' perspective could help to increase the understanding on these stakeholders' viewpoint of each self-consumption scheme, which have implications on the social acceptance of rooftop solar PV policy designs in the future.

CHAPTER 4
ECONOMIC RESULT AND DISCUSSION

4.1 Economic result of Residential sector

This section shows the economic result of economic simulation using the two types of residential tariffs: block rate and TOU rate. Figure 4.1 presents the relationship between the average daily load profiles (the blue line) versus the average daily PV production (the orange line) in 12 months. Typically, solar PV systems produce electricity during the day time (typically from 6 am.-5 pm) and generate the peak power mostly at noon time (12 pm). This PV electricity helps fulfill the electricity load during the daytime or otherwise consumers have to buy the electricity from the grid. On the other hand, when the electricity load is less than produced electricity from the solar PV system, the excess generation electricity would flow back into the grid as shown in the Figure 4.2 (in the orange line).

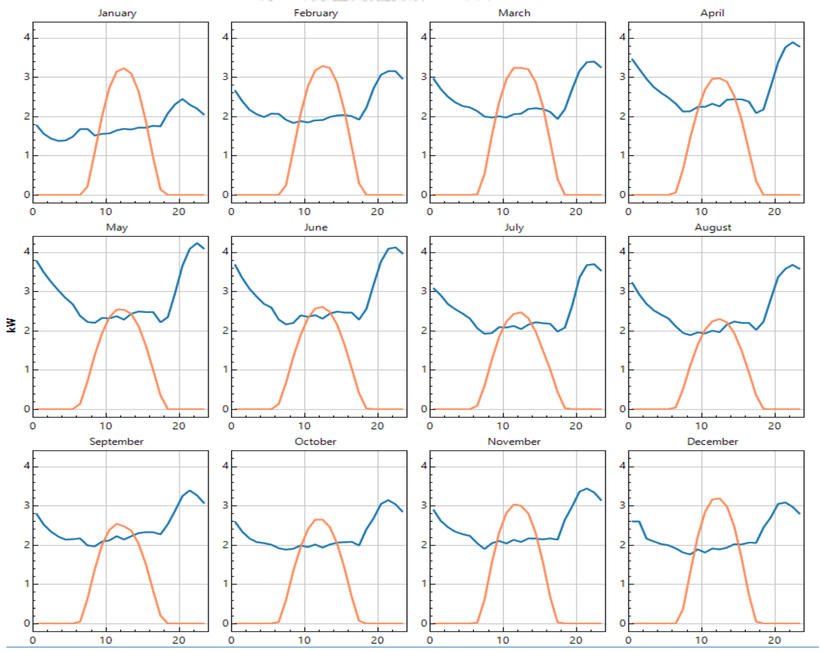

Figure 4.1: The relationship between average daily PV production (the orange line) and average daily electricity load (the blue line) in 12 months.

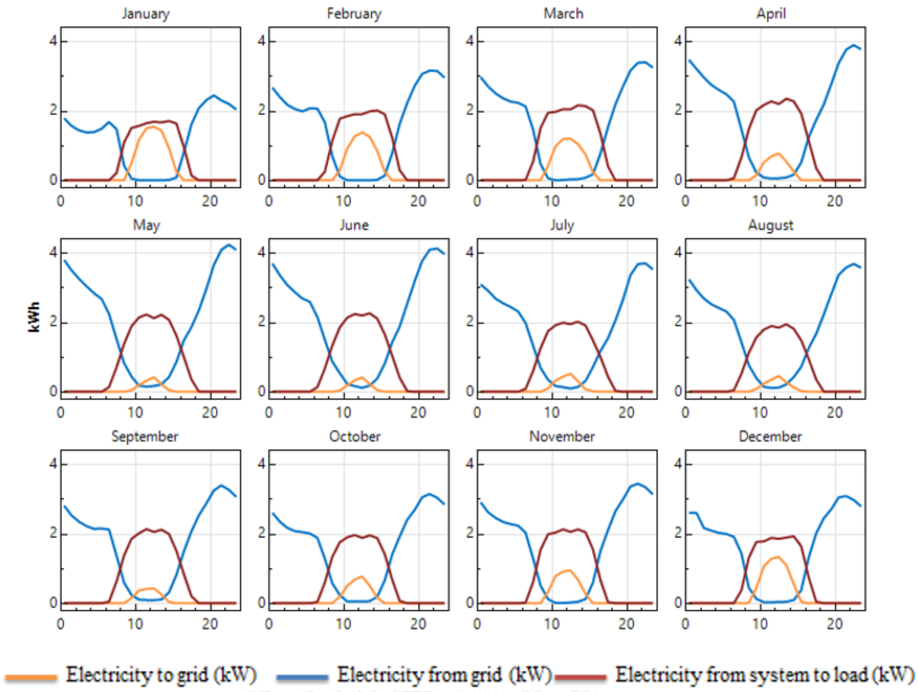

Figure 4.2: The relationship of electricity system to load (the red line), electricity to grid (the orange line), and electricity from grid (the blue line) in 12 months.

Table 4.1 presents the summary of performance output of the 5 kW PV system. Without any supporting scheme, the net installation cost of 5 kW PV system is at 287,149 baht. The PV production is at 34 % of the annual energy consumed (PV/Load ratio = 34%). On the other hand, the assumed PV size and load might not be the optimal choice, depending on the compensation scheme for excess electricity. As shown in Figure 4.2, there is a lot of excess electricity during the day. This is because peak load occurs only once a year. Thus, it would be wasteful to install PV size to cover the peak load if excess generation is not compensated for. In order to maximize the profit for household PV installation, this research conducted sensitivity analysis with various PV/load ratios for both residential and commercial scales for three selected schemes to make the results stronger and see the which PV size gives the best financial outcome.

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Table 4.1: Summary of 5 kW PV system output.		
Data	Unit	Value
Net capital cost	THB	287,149
Capacity factor	%	16
Energy yield	kWh/kW	1,403
Electricity load	kW	21,280.64
PV production	kWh	7,306
Electricity from PV system that serve the load (Year 1)	kWh	6,030.3
Electricity to grid (excess generation) (Year 1)	kWh	1,27.5.7

4.1.1 Residential block rate

4.1.1.1 Thailand's self-consumption scheme

Table 4.2 presents the financial metrics of self-consumption scheme with no buyback rate for the residential block rate. The feasibility of this system includes a positive NPV of 312,034 THB, a payback period of 8.9 years, and an internal rate of return (IRR) of 12%. The net saving for self-compensation is equal to 25,167 THB (for year 1).

Table 4.2: Summary of residential self-consumption scheme, Block rate, installed capacity 5 kW.		
Metrics	Value	
Net present value (NPV)	312,034	THB
Payback period	8.9	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year1)	86,588	THB
Electricity bill with system (Year 1)	61,421	THB
Net saving with energy (Year 1)	25,167	THB

4.1.1.2 Net metering with rolling credit and wholesale buyback rate

Table 4.3 presents the financial metrics of net metering with rolling credit scheme at wholesale buyback rate. This scheme allows the excess part of electricity, which can be kept as credits to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 345,911 THB, and the payback period is 8.1 years. The IRR rate is 13%. The net saving for this scheme is equal to 30,495 THB (for year 1).

Table 4.3: Summary of residential net metering scheme, Wholesale buyback rate, installed capacity 5 kW.		
Metric	Value	
Net present value	345,911	THB
Payback period	8.1	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,572	THB
Electricity bill with system (Year 1)	56,077	THB
Net saving with energy (Year 1)	30,495	THB

4.1.1.3 Net metering with rolling credit and retail buyback rate

Table 4.4 presents financial metrics of net metering with rolling credit scheme at retail buyback rate. This scheme allows the excess part of electricity to be kept as credit to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 345,911 THB, and the payback period is 8.1 years. The IRR rate is 13%. The net saving for this scheme is equal to 30,495 baht (for year 1).

Table 4.4: Summary of residential net metering scheme, Retail buyback rate, installed capacity 5 kW		
Metric	Value	
Net present value	345,911	THB
Payback period	8.1	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,572	THB
Electricity bill with system (Year 1)	56,077	THB
Net saving with energy (Year 1)	30,495	THB

4.1.1.4 Net metering with rolling credit and premium buyback rate

This scheme allows the excess part of electricity to be kept as credits to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 345,911 THB, and the payback period is 8.1 years. The IRR rate is 13%. The net saving for this scheme is equal to 30,495 THB (for year 1).

Table 4.5 presents the financial metrics of net metering with rolling credit scheme at premium buyback rate.

Metric	Value	
Net present value	345,911	THB
Payback period	8.1	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,572	THB
Electricity bill with system (Year 1)	56,077	THB
Net saving with energy (Year 1)	30,495	THB

4.1.1.5 Net billing with real-time, wholesale buyback rate

Table 4.6 presents financial metrics of net metering with rolling credit and wholesale buyback rate. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at wholesale rate. The NPV for this scheme is a positive value of 336,747 THB, and the payback period is 8.3 years. The IRR rate is 13%. The net saving for this scheme is equal to 23,794 THB (for year 1)

Table 4.5: Summary of residential net billing (real-time) scheme, Wholesale buyback rate, installed capacity 5 kW.

Metric	Value	
Net present value	336,747	THB
Payback period	8.3	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,588	THB
Electricity bill with system (Year 1)	62,794	THB
Net saving with energy (Year 1)	23,794	THB

4.1.1.6 Net billing with real-time, retail buyback rate

Table 4.7 presents the financial metrics for net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at retail rate. The NPV for this scheme is a positive value of 342,214 THB, and the payback period is 8.2 years. The IRR is 13%. The net saving for this rate is higher than wholesale rate at 29,908 THB (for year 1).

Table 4.6: Summary of residential net billing (real-time) scheme, Retail buyback retail rate, installed capacity 5 kW.		
Metric	Value	
Net present value	342,214	THB
Payback period	8.2	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,588	THB
Electricity bill with system (Year 1)	56,681	THB
Net saving with energy (Year 1)	29,908	THB

4.1.1.7 Net billing with real-time, premium buyback scheme

Table 4.8 presents the financial metrics for net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at a premium rate. The NPV for this scheme is a positive value of 345,227 THB with a payback period of 8.1 years. The IRR is equal to 12%. Not surprisingly, the net saving for this rate is better than wholesale and retail rate at 30,381 baht (for year 1).

Table 4.7: Summary of residential net billing (real-time) scheme, Premium buyback rate, installed capacity 5 kW.		
Metric	Value	
Net present value	345,227	THB
Payback period	8.1	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	86,588	THB
Electricity bill with system (Year 1)	56,207	THB
Net saving with energy (Year 1)	30,381	THB

4.1.1.8 Sensitivity analysis results of residential block rate

In this sensitivity analysis, I calculated PV-to-load ratio at varying percentages (20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, and 120%). As described earlier, the PV-to-Load ratio is the total production of the PV system in a year, divided by the total load in a year. It therefore measures how large the PV system's size is relative to the energy consumption. This sensitivity analysis hence shows how the varying of PV system sizing impact consumers' feasibility across three schemes, namely Thailand's self-consumption scheme, net metering with rolling credit and buyback, and net billing with real-time buyback (no rolling credit).

The output of sensitivity analysis shows how it affects NPV and payback period of residential and commercial rooftop PV systems in three schemes.

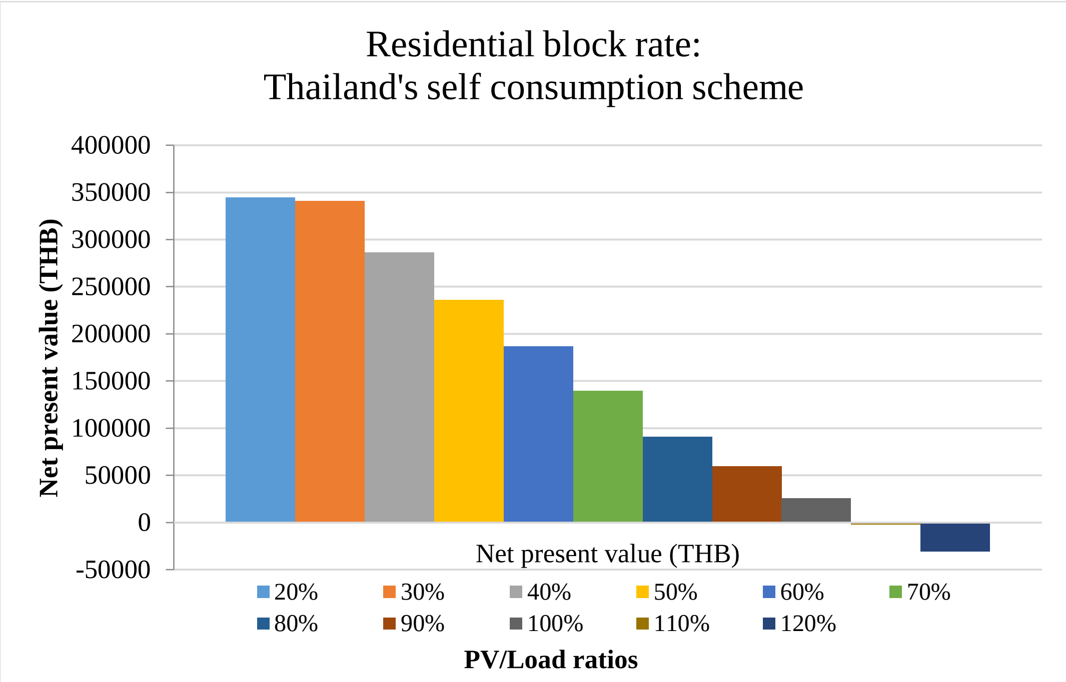


Figure 4.3 NPV of residential block rate-Thailand's self-consumption scheme

- Figure 4.3 shows that when PV-to-Load ratio exceeds 20%, the NPV declines. In the analysis range, NPV is maximized at the PV-to-Load Ratio of 20%. Meanwhile, NPV becomes negative at a PV-to-Load ratio of 120%.
- In the base case research, the PV-to-load ratio is 34%. The findings above suggested that the sizing of 5kW can be reduced further to increase the feasibility under Thailand self's consumption scheme.

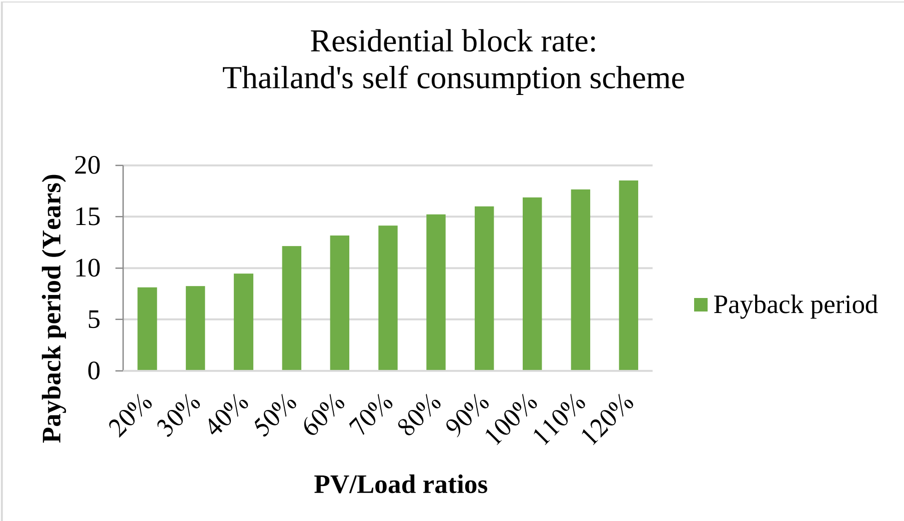


Figure 4.4: Payback period of residential block rate-Thailand’s self-consumption scheme

- Under Thailand’s self-consumption scheme and residential block rate, the PV-to-Load ratio of 20% gives the shortest payback period, compared to other PV-to-Load ratios in this analysis.
- Based on the output of the sensitivity analysis, researcher suggested that, under the self-consumption scheme, the PV system size should match or be less than load consumption. Since the excess generation of PV electricity would gain no compensation.

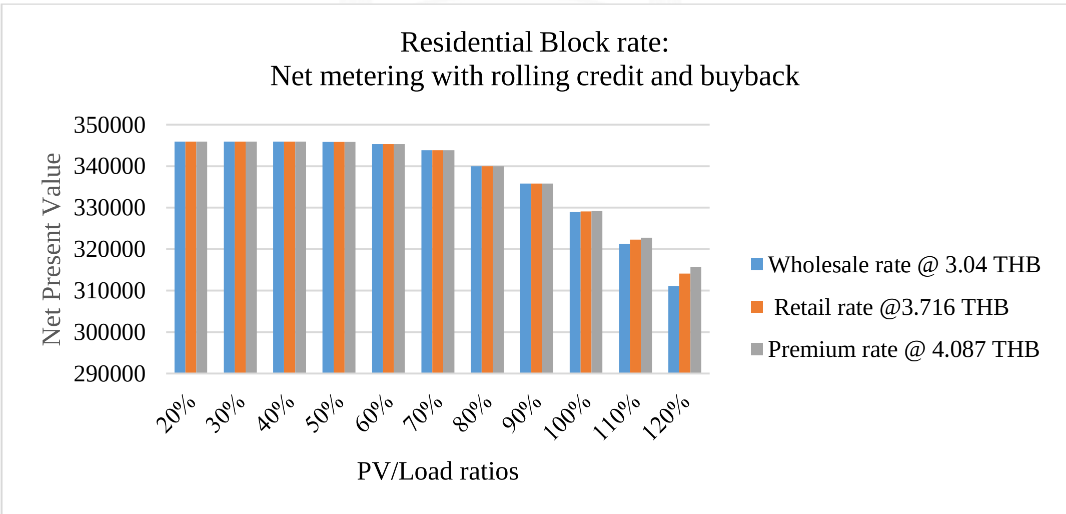


Figure 4.5: Net present value of residential block rate-net metering with rolling credit and buyback

- Under the net metering with rolling credit and buyback and block rate schemes, the sensitivity analysis shows that all NPVs from all PV-to-load ratios selected for this analysis are positive values.
- Based on Figure 4.5, when PV-to-load ratio exceeds 60%, the NPV begins to decline gradually. However, the PV-to-Load ratios between 20-60% yield the same value of NPV.
- Researcher suggested that install PV system less than or equal to load consumption can be the most feasibility for investment in this scheme. When net metering with rolling credit and buyback is the compensation scheme, and the consumers use the block rate, this research advises that PV system sizing can be matched or slightly higher than load consumption in order to gain compensation from excess generation.

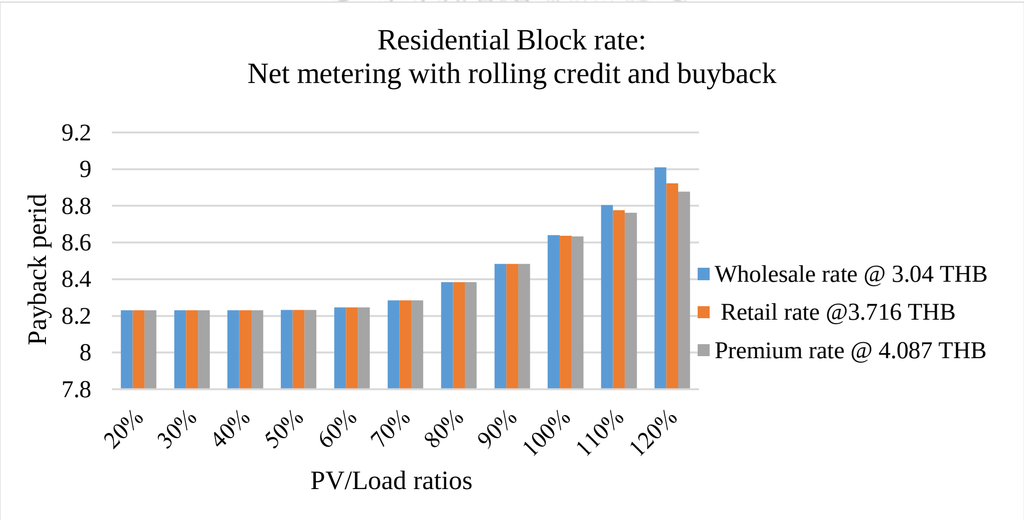


Figure 4.6: Payback period of residential block rate: Net metering with rolling credit and buyback

- Similar to the results on NPV, Figure 4.6 shows that PV-to-load ratios between 20%-60% are the most feasible for residential block rate with net metering rolling credit and buyback because they yield the shortest payback periods.

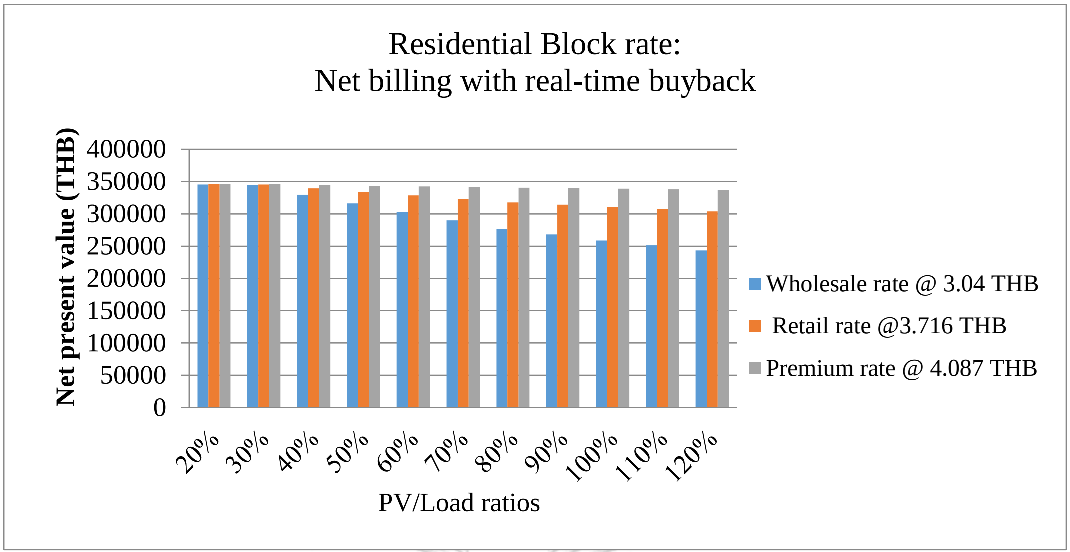


Figure 4.7: NPV of residential block rate: Net billing with real-time buyback

- The output of this sensitivity analysis shows that PV-to-load ratios between 20% and 30% are the most feasible ratio for residential block rate for the three buyback rates.
- Premium rate is the most feasible buyback rate for every PV-to-load ratio for this scheme with the highest NPV positive values.
- Based on Figure 4.7, when PV-to-load ratios exceed 30%, the NPV begins to reduce for all the buyback rates. The lower the buyback rate, the faster the NPV declines.
- When net billing with real-time buyback below retail rate is used as the compensation scheme, and the consumer uses the block rate, this research advises that PV system sizing should match or be less than load consumption in order to maximize compensation from excess generation. This is because the buyback rate below retail rate reduces the value of excess generation significantly.

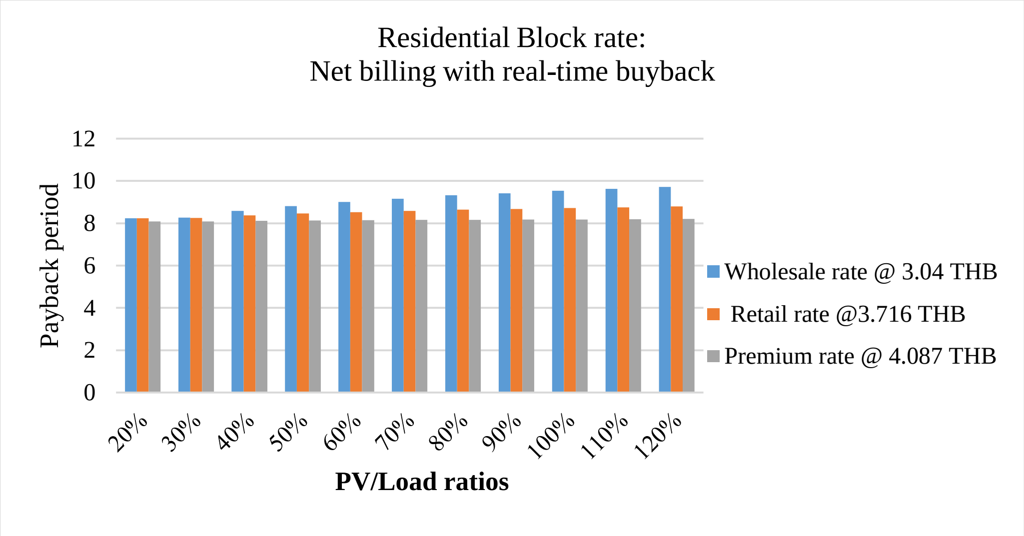


Figure 4.8: Payback period of residential block rate: Net billing with real-time buyback

- Similar to the result of sensitivity analysis of NPV, Figure 4.8 shows that the higher PV-to-load ratio, the longer the payback period, except premium rate that enables the payback period to stay the same in every PV-to-load ratio.

In addition, PV-to-load ratios between 20%-30% gives the shortest payback period for residential block rate with net billing with real-time buyback, compared to other PV-to-Load ratios in this analysis.

4.1.1.9 Discussion and summary of economic result of residential block rate in three schemes

Table 4.8: Summary of economic feasibility of residential block rate in Three types of self-consumption schemes, installed capacity 5 kW.

	Residential Block rate						
	Thailand's Self-consumption scheme	Net metering with rolling credit and buyback			Net billing with real-time buy-back		
Buyback rate	**0**	**3.043**	**3.716**	**4.087**	**3.043**	**3.716**	**4.087**
Annual energy (year 1), kWh	7,306	7,306	7,306	7,306	7,306	7,306	7,306
Capacity factor (year 1), %	16	16	16	16	16	16	16
Net present value, THB	**312,034**	**345,911**	**345,911**	**345,911**	**336,747**	**342,214**	**345,227**
Payback period, Year	**8.9**	**8.1**	**8.1**	**8.1**	**8.3**	**8.2**	**8.1**
IRR ,%	**12**	**13**	**13**	**13**	**13**	**13**	**12**
LCOE nominal, THB/kWh	3.45	3.45	3.45	3.45	3.45	3.45	3.45
LCOE Real, THB/kWh	3.03	3.03	3.03	3.03	3.03	3.03	3.03

Comparing the feasibility results across the three schemes, the results in terms of NPVs, IRRs, and PBs are different due to the different buyback rates and different compensation methods. As shown in Table 4.9, the net metering schemes with three different buyback rates, wholesale, retail, and premium buyback are the most profitable scheme among three schemes because they yield the highest NPV (345,911) and the lowest payback period (8.1 years). The results of net metering scheme also show the same values of NPV and Payback period. This can be explained by Figure 4.9, which indicates that the total energy consumed (882,887.9 kWh) is greater than total energy produced from PV system (172,100 kWh) for the whole year as shown in Figure 4.3. Therefore, there is no net electricity production left at the end of the year. With no electricity left at the end of the year, the varying of buyback rates under these net metering schemes affect the economics of the schemes.

For the results of net billing schemes with three different buyback rates, wholesale, retail, and premium buyback as shown in Table 4.9 are slightly less than the values of NPV, PB, and IRR of net metering schemes in residential block rate. Not surprisingly, net billing with premium buyback rate gives the highest NPV (345,227 THB) and the shortest payback period (8.1 years), but still not attractive, compared to the results of net metering with rolling credit and buyback.

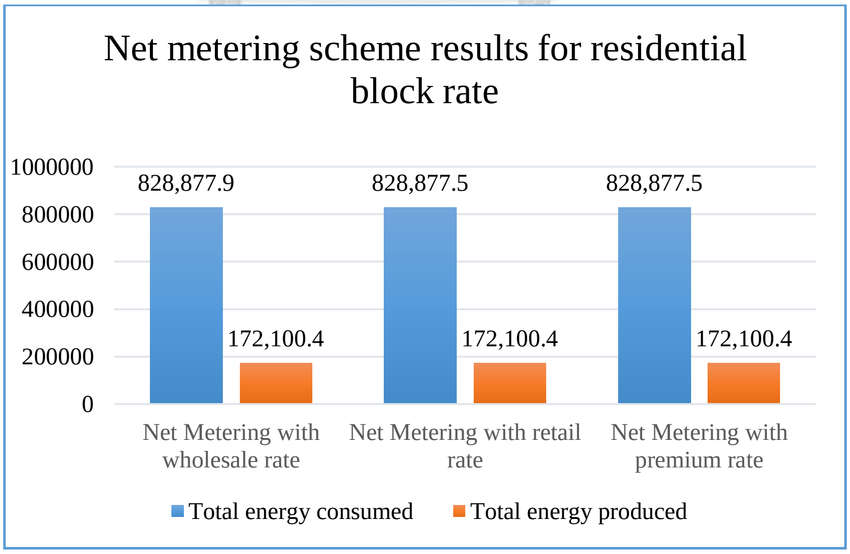


Figure 4.9: net metering scheme results of residential block rate

Across all schemes, the levelized cost of electricity was the same at 3.45 THB/kWh, which is lower than retail electricity rate (3.97 baht/kWh). It can be said that the cost of producing solar PV is lower than buying electricity from the grid. This point is called "grid parity" that could accelerate rooftop solar PV adoption. As will be seen in other cases, the LCOE of a 5kW system is the same regardless of the compensation scheme because its calculation only takes into account the costs associated with the system. Therefore, if LCOE is used as the main indicator for judging the attractiveness of the project, a 5 kW PV system is already attractive for residential households that subscribe to the block rate and has the same load profile as the one used in this research.

4.1.2 Residential TOU rate

4.1.2.1 Thailand's self-consumption scheme

Table 4.10 presents the financial metrics of self-consumption scheme with no buyback in residential TOU rate. The feasibility of this system includes a positive NPV of 351,319 THB, a payback period of 8.6 years, and an IRR of 13%. The net saving for self-compensation scheme is equal to 26,458 THB (for year 1). These results are slightly higher than the feasibility of the residential block rate.

Table 4.9: Summary of residential self-consumption with no buyback, Installed capacity 5 kW.

Metric	Value	
Net present value	351,319	THB
Payback period	8.6	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	76,521	THB
Electricity bill without system (Year 1)	50,063	THB
Net savings with system (Year 1)	26,458	THB

4.1.2.2 Net metering with rolling credit and wholesale buyback rate

Table 4.11 presents the financial metrics of net metering with rolling credit and wholesale buyback rate. This scheme allows the excess part of electricity to be kept as credit (in kWh) to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 234,015 THB, and the payback period of 7.7 years. The IRR is 13%. The net saving for this scheme is equal to 31,783 THB (for year 1).

Table 4.10: Summary of residential net metering scheme, Wholesale buyback, installed capacity 5 kW.		
Metric	Value	
Net present value	234,015	THB
Payback period	7.7	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	75,930	THB
Electricity bill without system (Year 1)	44,146	THB
Net savings with system (Year 1)	31,783	THB

4.1.2.3 Net metering with rolling credit and retail buyback rate

Table 4.12 presents financial metrics of net metering with rolling credit and retail buyback rate. This scheme allows the excess part of electricity to be kept as credit (in kWh) to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 234,015 THB, and the payback period 7.7 years. The IRR is 13%. The net saving for this scheme is equal to 32,375 baht (for year 1).

Table **4**.11: Summary of residential net metering scheme Retail buyback rate, installed capacity 5 kW.		
Metric	Value	
Net present value	234,015	THB
Payback period	7.7	Years
Internal rate of return (IRR)	13	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	76,521	THB
Electricity bill without system (Year 1)	44,146	THB
Net savings with system (Year 1)	32,375	THB

4.1.2.4 Net metering with rolling credit and premium buyback rate

Table 4.13 presents the financial metrics of net metering with rolling credit and premium buyback rate. This scheme allows the excess part of electricity to be kept as credit (in kWh) to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 283,328 THB, and the payback period is 6.5 years. The IRR is 15%. The net saving for this scheme is equal to 32,375 THB (for year 1).

Table **4**.12: Summary of residential net metering scheme, Premium buyback rate, installed capacity 5 kW.

Metric	Value	
Net present value	283,328	THB
Payback period	6.5	Years
Internal rate of return (IRR)	15	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	76,521	THB
Electricity bill without system (Year 1)	44,146	THB
Net savings with system (Year 1)	32,375	THB

4.1.2.5 Net billing with real time wholesale buyback rate

Table 4.14 presents the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at a wholesale rate. The NPV for this scheme is a positive value of 371,975 THB and the payback period of 7.9 years. The IRR rate is 14%. The net saving for this scheme is equal to 30,732 THB (for year 1).

Table 4.13: Summary of residential net billing (real-time) scheme Wholesale buyback, installed capacity 5 kW

Metric	**Value**	
Net present value	371,975	THB
Payback period	7.9	Years
Internal rate of return (IRR)	14	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	76,521	THB
Electricity bill without system (Year 1)	45,789	THB
Net savings with system (Year 1)	30,732	THB

4.1.2.6 Net billing with real time retail buyback rate

Table 4.15 shows the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at a retail rate. The NPV for this scheme is a positive value of 388,953

THB, and the payback period is 7.7 years. The IRR rate is 14%. The net saving for this scheme is equal to 32,340 THB (for year 1).

Table 4.14: Summary of residential net billing (real-time) scheme Retail buyback, installed capacity 5 kW

Metric	Value	
Net present value	388,953	THB
Payback period	7.7	Years
Internal rate of return (IRR)	14	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	76,525	THB
Electricity bill without system (Year 1)	44,185	THB
Net savings with system (Year 1)	32,340	THB

4.1.2.7 Net billing with real time premium buyback rate

Table 4.16 presents the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at a premium rate. The NPV for this scheme is a positive value of 480,943 THB, and a payback period of 7.0 years. The IRR is at 16%. Not surprisingly, the net saving for this rate is better than wholesale and retail rate at 36,070 THB (for year 1).

Table 4.15: Summary of residential net billing (real-time) scheme Premium buyback, installed capacity 5 kW

Metric	Value	Unit
Net present value	480,943	THB
Payback period	7.0	Years
Internal rate of return (IRR)	16	%
Levelized COE (nominal)	3.45	THB/kWh
Levelized COE (Real)	3.03	THB/kWh
Electricity bill without system (Year 1)	97,607	THB
Electricity bill without system (Year 1)	61,537	THB
Net savings with system (Year 1)	36,070	THB

4.1.2.8 Sensitivity analysis of residential TOU rate

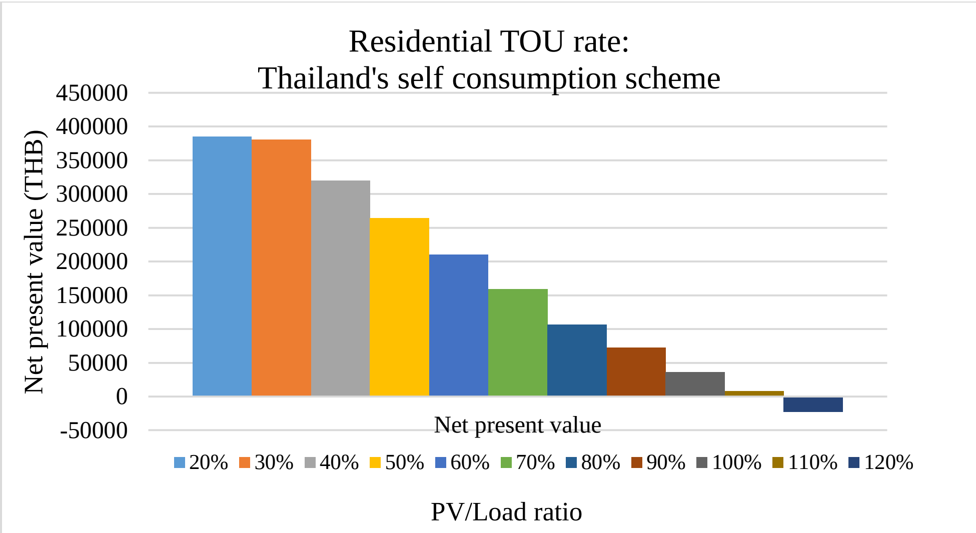


Figure 4.10: NPV of residential TOU rate: Thailand's self-consumption scheme

- Figure 4.10 shows that the PV-to-load ratio of 20% gives the highest positive NPV values, while NPV value becomes negative at a PV-to-load ratio of 120%.
- The output of this sensitivity analysis indicates that the NPV decreases when the PV-to-load ratio exceeds 20%.
- In the base case research, the PV-to-load ratio is 34%. The findings above suggested that the sizing of 5kW can be reduced further to increase the feasibility under from Thailand's self-consumption scheme.

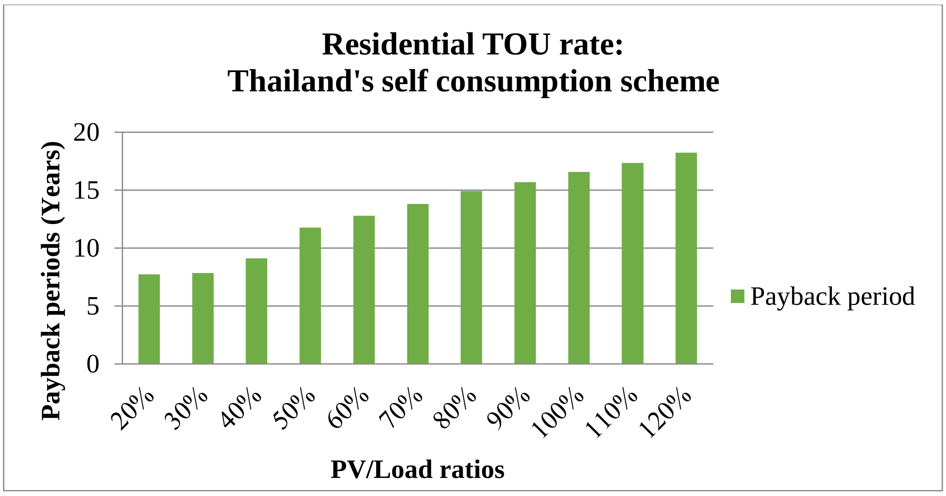


Figure 4.11: Payback period of residential TOU rate: Thailand's self-consumption scheme

- Under Thailand's self-consumption scheme and residential TOU rate, the PV-to-Load ratio of 20% gives the lowest payback period, compared to other PV-to-Load ratios in this analysis. Meanwhile, when the PV-to-Load ratio exceeds 20%, the payback period increases.
- Based on the outputs of this sensitivity analysis, researcher suggested that under the self-consumption scheme, the PV system size should match or be less than load consumption. Since the excess generation of PV electricity would gain no compensation.

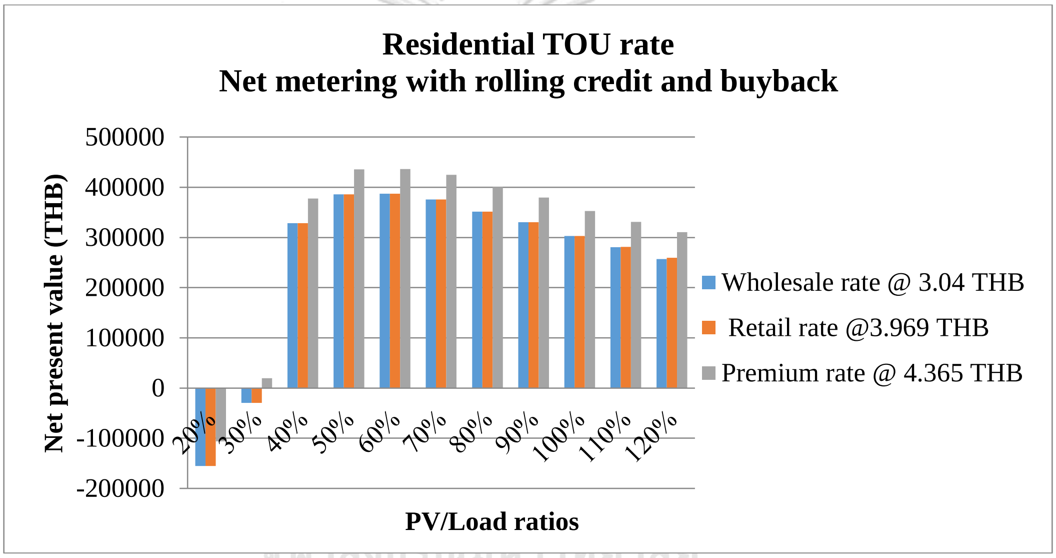


Figure 4.12: Net present value of residential TOU rate: Net metering with rolling credit and buyback

- Under the net metering with rolling credit and buyback scheme, the sensitivity analysis shows that the PV-to-Load ratios between 40% and 120% give positive NPV values, while PV-to-Load ratios between 20% and 30% show negative NPV values. This is due to there might have less or no excess credits beyond these PV-to-Load ratios under this scheme. Therefore, NPV can become negative values when PV system sizing (5kW) is less than load consumption, compared to based case research (PV-to-Load ratios 34%).
- However, NPV declines when PV-to-Load ratio exceeds 60%.

- Based on the output of the sensitivity analysis in Figure 4.12, research suggested that, under net metering with rolling credit and buyback in residential TOU rate, 5kW sizing can be increased further under this scheme to offset compensation from excess generation, compared to base case research (PV-to-Load ratio 34%).

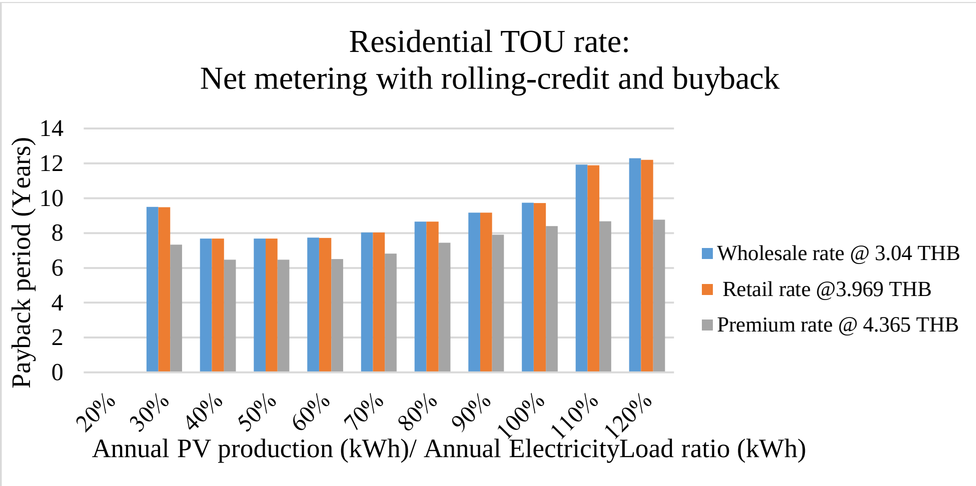


Figure 4.13: Payback period of residential TOU rate: Net metering with rolling credit and buyback

- The output of this sensitivity analysis shows that PV-to-Load ratios between 40 and 50% give the shortest payback period, compared to other PV-to-Load ratios in this analysis.
- Researcher suggested that PV system can be sized slightly higher than load consumption in order to gain compensation for the excess part of electricity.

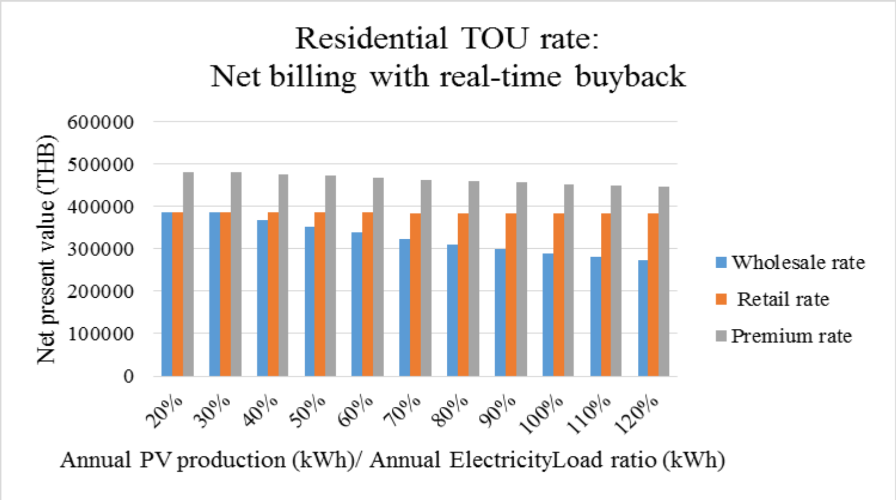


Figure 4.14: NPV of residential TOU rate: Net billing with real-time buyback

- The outputs of this sensitivity analysis show that all NPVs from all PV-to-Load ratios selected to this analysis are positive values.
- The PV-to-Load ratios between 20%-30% yield the highest NPV values, while the NPV declines when the PV-to-Load ratios exceeds 30%.
- As the buyback rate decreases and PV-to-Load ratios increase, the NPV declines at a faster rate.
- In the based case research, the PV –to-Load ratio is 34%. Hence, based on this sensitivity analysis, researcher suggested that under net billing with real-time buyback scheme, the sizing of 5 kW can be reduced further to increase feasibility for this scheme.

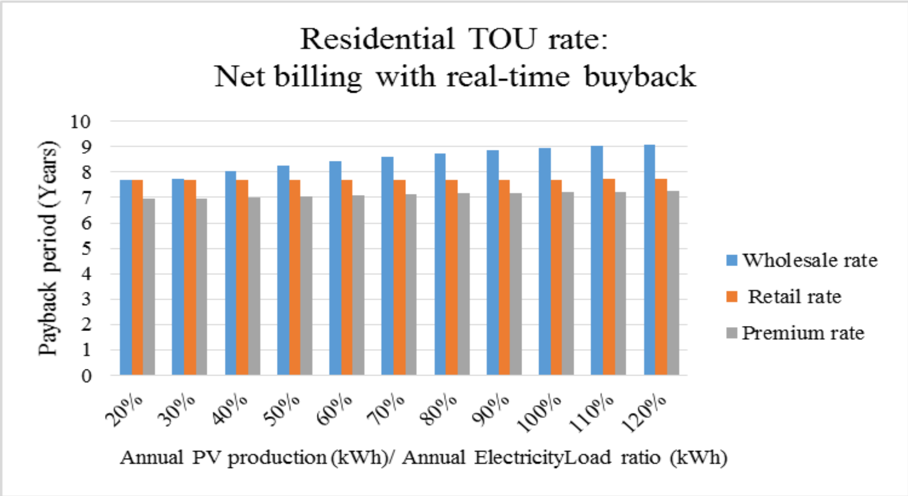


Figure 4.15: Payback period of residential TOU rate: Net billing real-time buyback

- Similarly, PV-to-Load ratio between 20% and 30% give the shortest payback period under net billing with real-time buyback scheme, compared to other PV-to-Load ratios in this analysis.
- As the buyback rate declines and PV-to-Load ratios increase, the payback period increases at a faster rate.
- Based on the output of this sensitivity analysis, this research advised that 5kW sizing can be reduced further to increase the feasibility under net billing with real-time buyback, compared to base case research (PV-to-Load ratio 34%).

4.1.2.9 Discussion and summary of economic result of residential TOU rate in three schemes

Comparing the feasibility results across the three schemes, the results in terms of NPVs, IRR, and PBs are different due to the different buyback rates and different compensation methods. As shown in Table 4.17, the net metering schemes with three different buyback rates, wholesale, retail, and premium buyback are the most profitable scheme due to their shortest payback periods.. Premium buyback rate yields the shortest payback period (6.5 years), while wholesale and retail buyback rate yield the same values of payback period (7.7 years).

It should be noted that for residential TOU analysis, the net billing schemes yield NPVs that are higher than the net metering schemes (Table 4.17). This result is in contrast to the case of residential block rate discussed in Section 4.1.1. This is due to the way in which the SAM model accounts for excess credits in net-metering under TOU rate. Excess credits from peak period are used to offset consumption during peak period in the following billing period. However, if not all consumption during peak hours can be offset, then the excess peak credits will offset the off-peak consumption, thereby significantly reducing the value of excess PV. In this analysis, it was found that the excessed credits of net metering with rolling credit and buyback cannot offset all of peak consumption during the peak hours of the following periods. This means some excess generation was used to offset consumption in the off-peak hours at the values that were less than on-peak values as shown in Table 4.17. Therefore, the NPVs of net billing with real-time buyback became more attractive than net metering with rolling credit and buyback at all three buyback rates.

Table 4.16: Summary of residential TOU rate in three schemes, 5 kW PV sizing.

	Residential TOU rate						
	Thailand's Self-consumption scheme	**Net metering with rolling credit and buyback**			**Net billing with real-time buy-back**		
Buyback rate	**0**	**3.043**	**3.969**	**4.365**	**On peak= 3.89 Off peak = 2.02**	**On peak= 5.55 Off peak = 2.29**	**On peak= 5.73 Off peak = 2.43**
Annual energy (year 1), kWh	7,306	7,306	7,306	7,306	7,306	7,306	7,306
Capacity factor (year 1), %	16	16	16	16	16	16	22
Net present value, THB	**351,319**	**234,015**	**234,015**	**283,328**	**371,975**	**388,953**	**480,943**
Payback period, Year	**8.6**	7.7	7.7	6.5	**7.9**	7.7	**7.0**
IRR ,%	**13**	**13**	**13**	**15**	**14**	**14**	**16**
LCOE Nominal, THB/kWh	3.45	3.45	3.45	3.45	3.45	3.45	3.45
LCOE Real THB/kWh	3.03	3.03	3.03	3.03	3.03	3.03	3.03

4.1.3 Comparative results between block rate and TOU rate of residential households.

Table 4.17: Comparison of economic feasibility between residential block rate and TOU rate.

	Residential Block rate						
	Thailand' s Self-consumption scheme	Net metering with rolling credit and buyback			Net billing with real-time buy-back		
Buyback rate	**0**	**3.043**	**3.716**	**4.087**	**3.043**	**3.716**	**4.087**
Annual energy (year 1), kWh	7,306	7,306	7,306	7,306	7,306	7,306	7,306
Capacity factor (year 1), %	16	16	16	16	16	16	16
Net present value, THB	**312,034**	**345,911**	**345,911**	**345,911**	**336,747**	**342,214**	**345,227**
Payback period, Year	**8.9**	**8.1**	**8.1**	**8.1**	**8.3**	**8.2**	**8.1**
IRR ,%	**12**	**13**	**13**	**13**	**13**	**13**	**12**
LCOE nominal, THB/kWh	3.45	3.45	3.45	3.45	3.45	3.45	3.45
LCOE Real, THB/kWh	3.03	3.03	3.03	3.03	3.03	3.03	3.03

	Residential TOU rate						
	Thailand's Self-consumption scheme	**Net metering with rolling credit and buyback**			**Net billing with real-time buy-back**		
Buyback rate	**0**	**3.043**	**3.969**	**4.365**	**On peak= 3.89 Off peak = 2.02**	**On peak= 5.55 Off peak = 2.29**	**On peak= 5.73 Off peak = 2.43**
Annual energy (year 1), kWh	7,306	7,306	7,306	7,306	7,306	7,306	7,306
Capacity factor (year 1), %	16	16	16	16	16	16	22
Net present value, THB	**351,319**	**234,015**	**234,015**	**283,328**	**371,975**	**388,953**	**480,943**
Payback period, Year	**8.6**	**7.7**	**7.7**	**6.5**	**7.9**	**7.7**	**7.0**
IRR ,%	**13**	**13**	**13**	**15**	**14**	**14**	**16**
LCOE Nominal, THB/kWh	3.45	3.45	3.45	3.45	3.45	3.45	3.45
LCOE Real THB/kWh	3.03	3.03	3.03	3.03	3.03	3.03	3.03

The overall results of economic feasibility between residential block rate and TOU rate are presented in Figure 4.18, showing that net metering with rolling credit and buyback scheme is the most economically feasible for residential 5 kW PV system investment. For residential block rate, net metering with rolling credit and buyback shows the highest NPV and lowest payback period among three schemes as well as results in lowest payback period in residential TOU rate. Meanwhile, net billing with real-time buyback shows the highest NPV and IRR for the residential TOU rate. As mentioned above, the payback period is the main consideration in terms of customer investment perspective. Thus, net metering with rolling credit and buyback is the most economically feasible scheme for residential 5 kW rooftop PV system installations. Another consideration is the capital cost at 287,149 is still attractive to invest since this results in a nominal levelized cost of electricity (LCOE) (inflation rate included) of 3.45 THB/kWh, compared to the price of purchasing electricity at 3.716 THB/kWh. This point is called grid parity, which is reached when PV technology can produce electricity at a LCOE that is lower or equal to the rate of purchasing electricity.

4.2 Economic result of Commercial TOU rate

The net capital cost for a 100 kW PV system investment is equal to 5,485,930 THB. Figure 4.4 presents the relationship between the average daily load profiles (the blue line) versus the average daily PV production (the orange line) in 12 months for the Medium General Service. The installed capacity of this system was considered to account for 100% of peak demand (100 kW) in order to maximize the installed capacity to fully serve the load consumption. The shape of the load consumption versus electricity produced from PV system are similar, i.e. medium-sized enterprises used high electricity consumption during the day, which corresponds to the characteristics of solar power generation. This type of users could take advantage from rooftop solar PV system.

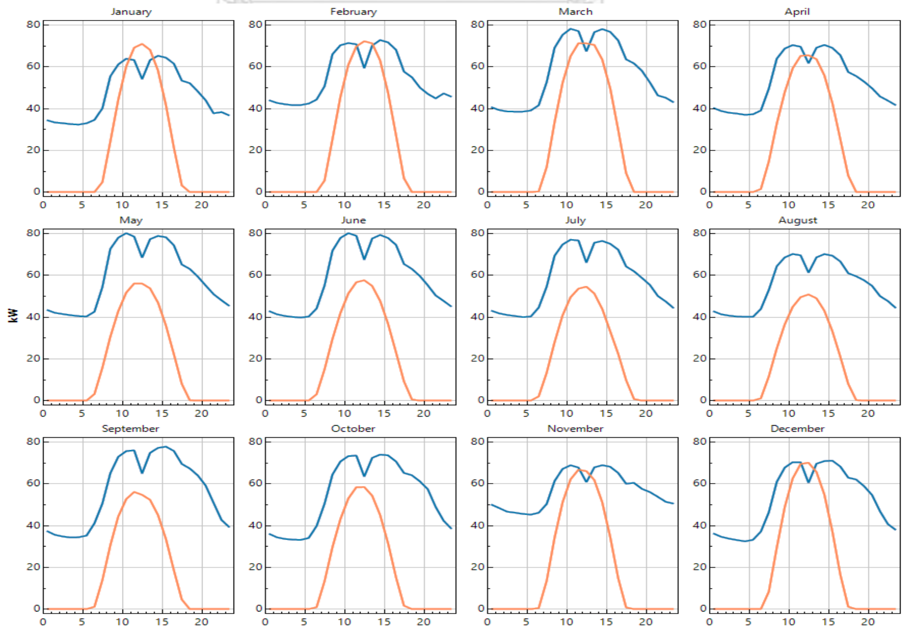


Figure 4.16: The relationship between average daily PV production (the orange line) and average daily electricity load (the blue line) in 12 months for Medium General Service; installed capacity 100 kW.

As a result of simulation data, PV production could serve on-peak load (the orange line) as shown in Figure 4.16, which could reduce the electricity from grid (the blue line). Although, at a time that solar PV system cannot generate electricity such as in early morning and at night, there is a need to buy electricity from grid. The high usage of electricity has changed from day load to night load due to the use of PV electricity during the daytime. So, rooftop solar PV system can provide the benefit in term of reducing the on-peak demand and reducing the electricity bill. On the other hand, some of the day when load consumption was less than PV production, part of that excess electricity would flow back into the grid as shown in red line the Figure 4.17.

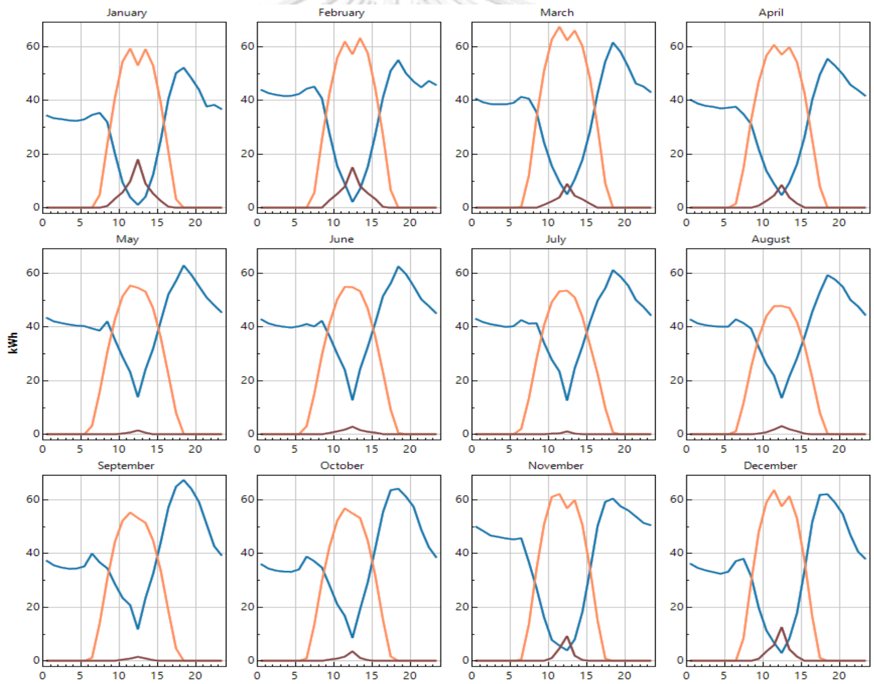


Figure 4.17: The relationship of PV production (the orange line), electricity load from grid (the blue line), and excess part of electricity (the red line) in 12 months of medium general business, with installed capacity 100 kW.

Table 4.19 shows the summary of performance output of a 100-kW PV system. Without any supporting schemes, the net installation cost of 100 kW PV system is at 5,485,930 THB. The PV production is at 33 % from annual energy consumed (PV/Load = 33%), which is 483,601.35 kWh and annual energy produced equal to 161,624 kWh.

Table 4.18: the summary of 100 kW PV system performance output		
Data	**Unit**	**Value**
Net capital cost	THB	5,485,930
Capacity factor	%	16.4%
Electricity yield	kWh/kW	1,440
PV production	kW	161,624
Electricity from PV system that serve the load (year 1)	kWh	154,683.58
Electricity to grid (excess generation) (Year 1)	kWh	6,940.78

4.2.1 Thailand's self-consumption scheme

Table 4.20 shows the financial metrics of self-consumption scheme with no buyback rate for the medium general business with TOU rate. The feasibility of this system includes a positive of 1,444,367 THB, a payback period of 8.4 years and IRR of 12%. The net saving for self-compensation scheme is equal to 551,550 THB (for year 1).

Table 4.19: Summary of medium general service of self-consumption with no buyback, installed capacity 100 kW.		
Metric	Value	
Net present value	1,444,367	THB
Payback period	8.4	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,639,900	THB
Electricity bill with system (Year 1)	1,088,349	THB
Net saving with energy (Year 1)	551,550	THB

4.2.2 Net metering with rolling credit and wholesale buyback rate

Table 4.21 shows the financial metrics of net metering with rolling credit and wholesale buyback rate. This scheme allows the excess part of electricity to be kept as credits (in kWh) to offset consumption until the end of banking period. The NPV for this scheme is a positive value of 1,546,495 THB, a payback period of 8.2 years, and IRR of 12%. The net saving for this scheme is equal to 577,804 THB (for year 1).

Table 4.20: Summary of medium general service of net metering with wholesale buyback, installed capacity 100 kW.		
Metrics	Value	
Net present value (NPV)	1,546,495	THB
Payback period	8.2	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,639,889	THB
Electricity bill with system (Year 1)	1,062,085	THB
Net saving with energy (Year 1)	577,804	THB

4.2.3 Net metering with rolling credit and retail buyback rate

Table 4.22 shows the financial metrics of net metering with rolling credit and retail buyback rate. This scheme allows the excess part of electricity to be kept as credit (in kWh) to offset compensation until the end of banking period at retail rate. The results show a positive NPV of 1,547,095 THB, a payback period of 8.2 years, and an IRR of 12%. The net saving for this scheme is equal to 577,861 THB (for year 1).

Table 4.21: Summary of medium general service of net metering with retail buyback, installed capacity 100 kW		
Metrics	Value	
Net present value	1,547,095	THB
Payback period	8.2	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,640,157	THB
Electricity bill with system (Year 1)	1,062,296	THB
Net saving with energy (Year 1)	577,861	THB

4.2.4 Net metering with rolling credit and premium buyback rate

Table 4.23 shows the financial metrics of net metering with rolling credit and premium buyback rate. This scheme allows the excess part of electricity to be kept as credit (in kWh) to offset compensation until the end of banking period. The results shown a positive NPV value of 1,546,495 baht, a payback period of 8.1 years, and IRR of 12%. The net saving for this scheme is equal to 577,804 THB (for year 1) as given in table 33.

Table 4.22: Summary of medium general service of net metering with premium buyback, installed capacity 100 kW		
Metrics	Value	
Net present value	1,546,495	THB
Payback period	8.2	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,639,889	THB
Electricity bill with system (Year 1)	1,062,085	THB
Net saving with energy (Year 1)	577,804	THB

4.2.5 Net billing with real-time wholesale buyback rate

Table 4.24 shows the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at wholesale rate. The NPV is a positive value of 1,442,236 THB, a payback period of 8.4 years, and IRR of 12%. The net saving for this scheme is equal to 551,580 THB (for year 1).

Table 4.23: Summary of medium general service of net billing (real-time) wholesale buyback, installed capacity 100 kW		
Metric	Value	
Net present value	1,442,236	THB
Payback period	8.4	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,640,152	THB
Electricity bill with system (Year 1)	1,088,571	THB
Net saving with energy (Year 1)	551,580	THB

4.2.6 Net billing with real-time retail buyback rate

Table 4.25 shows the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at retail rate. The results show an NPV of 1,444,965 THB, a payback period of 8.3 years, and an IRR rate is at 12%. The net saving for this scheme is equal to 551,580 THB (for year 1).

Table 4.24: Summary of medium general service of net billing (real-time) retail buyback, installed capacity 100 kW		
Metric	Value	
Net present value	1,444,965	THB
Payback period	8.3	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,640,152	THB
Electricity bill with system (Year 1)	1,088,571	THB
Net saving with energy (Year 1)	551,580	THB

4.2.7 Net billing with real-time premium buyback rate

Table 4.26 shows the financial metrics of net billing with real-time buyback. This scheme allows prosumers to gain their payment from the excess part of electricity from all hours at premium rate. The results show a positive NPV at 1,444,965 THB, a payback period of 8.3 years, and an IRR of 12%. The net saving for this scheme is equal to 551,580 THB (for year 1).

Table 4.25: Summary of medium general service of net billing (real-time) premium buyback, installed capacity 100 kW		
Metric	Value	
Net present value	1,444,965	THB
Payback period	8.3	Years
Internal rate of return (IRR)	12	%
Levelized COE (nominal)	2.76	THB/kWh
Levelized COE (Real)	2.47	THB/kWh
Electricity bill without system (Year 1)	1,640,152	THB
Electricity bill with system (Year 1)	1,088,571	THB
Net saving with energy (Year 1)	551,580	THB

4.2.8 Sensitivity analysis of commercial TOU rate in three schemes

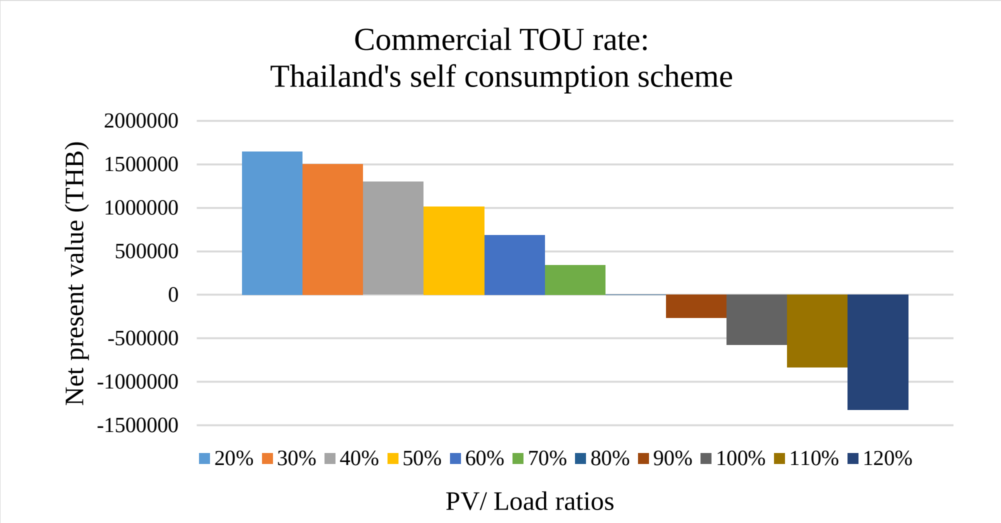


Figure 4.18: NPV of commercial TOU rate: Thailand’s self-consumption scheme

- Figure 4.18 shows that PV-to-Load ratio between 20 % and 80% gives the positive NPV values, while NPV is maximized at the PV-to-Load of 20% in the analysis range.
- Meanwhile, NPV becomes negative values when a PV-to-Load ratio exceeds 80%.
- In the base case research, the PV-to-Load ratio is 33%. The finding above suggested that the sizing of 100 kW can be reduced further to increase feasibility of rooftop PV system installation under Thailand’s self-consumption scheme.

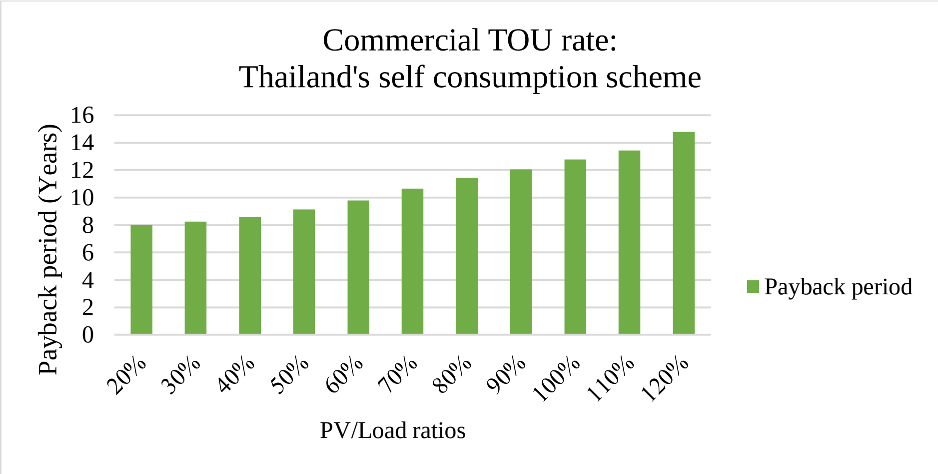


Figure 4.19: Payback period of commercial TOU rate: Thailand’s self-consumption scheme

- Similarly, a PV-to-load ratio of 20% gives the lowest payback period, compared to other PV-to-Load ratios in this analysis under Thailand’s self-consumption scheme and commercial TOU rate.
- Based on the outputs of this sensitivity analysis, the research advises that consumer should install PV system at appropriate size or less than load consumption in order to increase profitability, since the excess generation of electricity that flow back to the grid was not compensated.

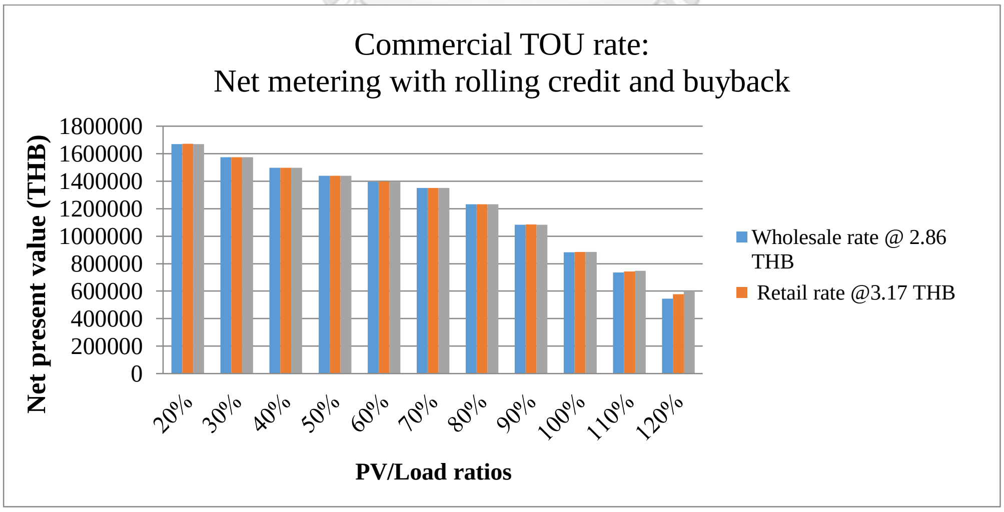


Figure 4.20: NPV of commercial TOU rate: Net metering with rolling credit and buyback

- The result of this sensitivity analysis shows that all NPVs from all PV-to-Load ratios are positive values, while the NPV is maximized at a PV-to-Load ratio of

20% for commercial TOU rate in net metering with rolling credit and buyback scheme.

- Based on Figure 4.20, when PV-to-Load ratio exceeds 20%, the NPV begin to decline. Compared to the base case research (PV/load ratio = 33%), this research advises that PV system should not more than 100 kW sizing in order to increase feasibility for consumer in TOU rate under net metering with rolling credit and buyback scheme.

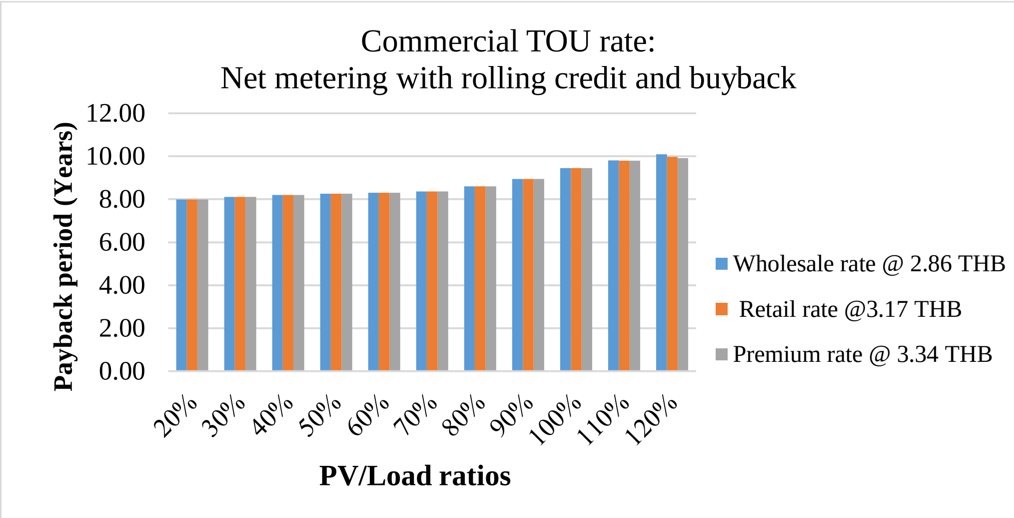


Figure 4.21: Payback period of commercial TOU rate: Net metering with rolling credit and buyback

- The result of sensitivity analysis shows that a PV-to-Load ratio of 20% gives the shortest payback period, compared to other PV-to-Load ratios in this analysis.
- Meanwhile, payback period starts to increase when PV-to-Load ratio exceeds 20%.
- Researcher suggested that PV system should not be sized higher than load consumption in order to gain the most feasibility of investment.

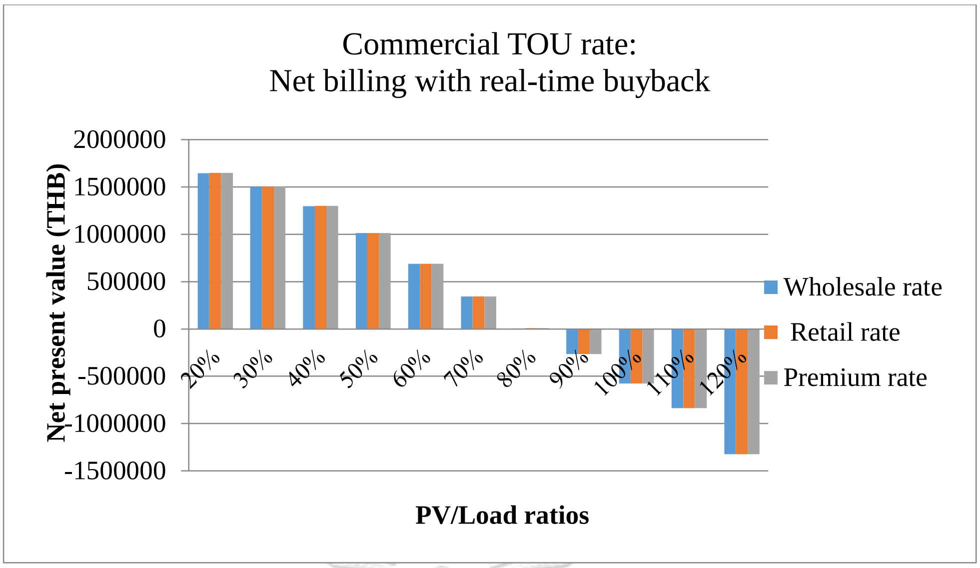


Figure 4.22: NPV of commercial TOU rate: Net billing with real-time buyback

- The output of this sensitivity analysis shows that NPVs from PV-to-Load ratios between 20% and 70% are positive values, while NPV is maximized at a PV-to-Load ratio of 20% under net billing with real-time buyback.
- The NPV begins to decline when PV-to-Load ratio exceeds 80%

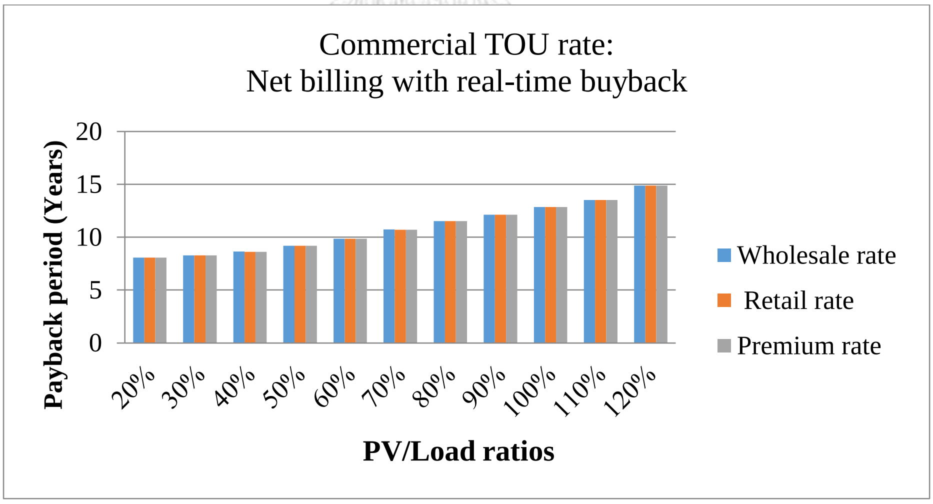


Figure 4.23: Payback period of commercial TOU rate: Net billing with real-time buyback

- Similarly, a PV-to-load ratio of 20% shows the lowest payback period for commercial TOU rate with net billing real-time buyback scheme.

- Meanwhile, payback period begins to increase when a PV-to-Load ratio exceeds 20%.
- Researcher suggested that PV system size should not be installed more than load consumption for the most feasibility of rooftop PV investment.

4.2.9 Discussion and summary of economic result of medium general business TOU rate

Table 4.26: Comparison of commercial TOU rate in three schemes, installed capacity 100 kW

	Medium General Business TOU rate						
	Thailand's Self-consumption scheme	Net metering with rolling credit and buyback			Net billing with real-time buy-back		
Buyback rate	**0**	**2.86**	**3.17**	**3.4**	**On peak= 3.89 Off peak = 2.33**	**On peak= 3.96 Off peak = 2.38**	**On peak= 4.14 Off peak = 2.5**
Annual energy (year 1), kWh	161,624	161,624	161,624	161,624	161,624	161,624	161,624
Capacity factor (year 1), %	16.4	16.4	16.4	16.4	16.4	16.4	16.4
Net present value, THB	**1,444,367**	**1,546,495**	**1,547,095**	**1,546,495**	**1,442,236**	**1,444,965**	**1,444,965**
Payback period, Year	**8.4**	**8.2**	**8.2**	**8.2**	**8.4**	**8.4**	**8.4**
IRR ,%	**12**	**12**	**12**	**12**	**12**	**12**	**12**
LCOE Nominal, THB/kWh	2.76	2.76	2.76	2.76	2.76	2.76	2.76
LCOE Real THB/kWh	2.47	2.47	2.47	2.47	2.47	2.47	2.47

Comparing the feasibility results across the three schemes, the results in terms of NPVs, IRRs, and PBs are different due to the different buyback rates and different compensation methods. As shown in Table 4.27, net metering with rolling credit and buyback with three different buyback rates, wholesale, retail, and premium buyback rate are the most profitable scheme among three schemes because they yield the highest NPV (1,546,495) and the lowest payback period (8.2 years). The NPV of this scheme is the same values. This is due to the fact that the total annual PV production was less than total annual load consumption, therefore, there was no net electricity production left at the end of the year.

It can be noticed that, for the commercial customer considered in this case, the two forms of compensation could not significantly affect to economic feasibility as compared to self-consumption scheme without compensation for the excess electricity.

Since most of electricity produced is fully self-consumed for reducing electricity demand during the daytime, and there is less or no excess part of electricity flew back into the grid. Thus, the compensation support measures for excess generation might not maximize the feasibility of investment.

CHAPTER 5
TECHNICAL RESULT AND DISCUSSION

This chapter analyzes technical factors that support or block the implementation of solar PV rooftop penetration in each type of self-consumption schemes, including net metering (rolling credit and buyback) and net billing (real-time buyback). This chapter is classified into two main parts: meter requirement and grid code for PV installation requirements, including inverter requirements.

5.1 Electricity meter

Electricity meter is a device used to measure the amount of electric energy that is consumed by the consumers. Utilities install electricity meters at homes, buildings and industries in order to measure the amount of electricity consumed for billing purposes. Most of electricity meters are calibrated in kilowatt-hour (kWh) unit and usually are read once at the end of each monthly billing period. Kilowatt hour is the basic unit of energy (Ramirez, 2006; Ridenour et al., 2001). There are different kinds of meters in the market, including uni-directional meter, bi-directional meter, electromechanical meter (with a rotating disk) as well as digital meter (Agarwal, 2014). Energy meter can be classified in regard to various factors such as: type of display such as analog or digital electric meter, type of meter point such as grid, secondary transmission, and end applications such as resident, commercial and industrial, and technical aspects such as single phase, three phases and accuracy class meters. Figure 5.1 shows the various forms of electricity meter uses.

Figure 5.1: Various forms of electricity meter

Source: (Agarwal, 2014)

5.1.1 Types of meter

This research focused on three kinds of electricity meter, namely electromechanical meter, electronic meter, and smart meter as follows:

5.1.1.1 Electromechanical meter

Electromechanical meter is the most common type of residential meter that is installed in both urban and rural areas. This type of kilowatt-hour meter has a rotating disk in it. It consists of rotating aluminum disc mounted on a spindle between two electro magnets. The working principle is simple. The disk's rotational speed is proportional to the amount of electricity consumed. When the power flow is high, then the disc rotates faster, and when the power flow is low, the disc rotates slower. So the electricity consumption is calculated in the electromechanical meter based on the cycles of rotating disc. The main problem of this type of meter is easily prone to tampering, leading to a requirement of an electrical energy monitoring system (Daware, 2016; NREL, 2002).

Electromechanical meter can be applied in various places such as homes, department stores, and industries, to charge electricity consumption by loads. In addition, this type of meter can also measure PV production from rooftop PV solar system. Basically, electromechanical meters are installed in accordance with the size of loads and therefore, it can be a single phase or three phase meters depending on the electric supply utilized by residential or commercial installations (NREL, 2002)as shown in Figure 5.2.

Figure 5.2: Mechanic meters for single-phase and three-phase
Source: (Mitsubishi Electric Automation, 2016)

5.1.1.2 Electronic meter

This type of meter has the ability to compute power accurately, with high precision and robustness of measuring instruments as compared to electromechanical meters, which are not able to accurately measure energy in the presence of phase-fixed load regulation schemes popular on distribution networks. Electronic meter consumes less power and begins measuring instantly when connected to load. This type of meter can be classified as electronic analog energy meter and digital energy meter. For analog meter, power is converted to be proportional frequency or pulse rate and it is integrated by counters placed inside it (Daigle, 2000).

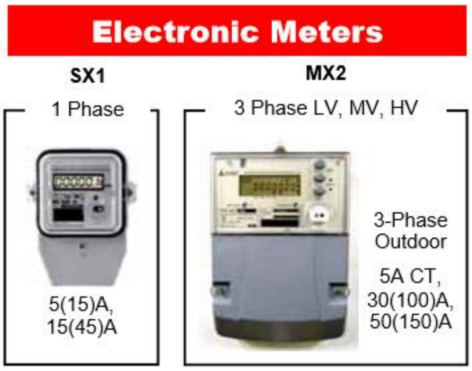


Figure 5.3: Electronic meters for single-phase and three-phase

Source: (Mitsubishi Electric Automation, 2016)

In digital electric meter, electricity is directly measured by digital signal processor or high performance microprocessors. This type of meter displays the readings of energy used on a digital display (LCD or LED). A digital meter comprises of instrument transformers (to sample current and voltage), analog to digital converters, microcontroller etc. The input voltage/current is compared to with a programmed reference voltage and current and then the data get converted into digital form. The power is integrated by logic circuits to get the energy and also for testing and calibration purpose. After that, it is converted to frequency or pulse rate. The digital data is the processed with proper operations in a microcontroller, which is then displayed on an LCD or LED display. Similar to the analog meter, voltage and current transducers are connected to a high resolution ADC (Daigle, 2000; Germer et al., 1991).

In China, digital electric meter have been deploying millions of single-phase meters and replacing electromechanical meter. There are three main reasons that China prefer digital meter as following:

(1). Accuracy and stability

Digital energy meters maintain their accuracy over a larger current range than the mechanical meter. They also are stable in terms of changes in temperature, voltage and line frequency.

(2). Simplified and lower cost of meter maintenance

The good point of digital energy meter is less maintenance as compared to conventional energy meter (Daigle, 2000)

Analog electric meter Digital electric meter

Figure 5.4: Analog and digital electric meter
Source: (Daware, 2016)

5.1.1.3 Smart meter

Smart electric meter is an electronic device used by utilities to communicate data for billing customers and operating electric system (An, 2011). The idea behind is simply to conserve energy and lower energy costs. For household-level electricity load data collected via smart metering could provide considerable opportunities. The accuracy of smart meter has been developed to improve the older electromechanical meter technology. Smart meters can register real-time energy consumption, including voltage, phase angle and frequency measures (Rodriguez-Calvo et al., 2017). Smart meters represent a combination of the electric meters with two-way communication technology for information, monitor, and control, which is commonly referred to as Advanced Metering Information (AMI) (Sunshine, 2017)

Figure 5.5: Smart meter one phase and three phase

Source: (Mitsubishi Electric Automation, 2016)

Smart meters have been implemented in some European countries such as Italy, Finland, and Sweden, and around 70% of European households are expected to have them by 2020 (Rodriguez-Calvo et al., 2017). Smart meters can be beneficial to electric utilities by eliminating manual meter reading, enabling them to monitor the electric system more quickly, provide real-time data useful for balancing electric loads and reducing power blackouts, allowing the use of dynamic pricing (raising or lowering the cost of electricity based on demand). For the consumer side, smart meter can provide benefits by offering more detailed feedback on energy use, helping to adjust their electricity consumption habit, and reducing electric outage and system-wide electric failures (Sharma et al., 2015). For transmission and distribution systems, smart meter can help with transformer load management, improve data for efficient grid system design. However, smart meter has its pros and cons, which might be challenges and costs to electric utilities in terms of transitioning to new technology and processes and also relate to a long-term financial commitment to the new meter technology and software associated.

5.1.2 Analysis of the types of meters for each types of self-consumption schemes

This section compares the use of electricity meter for each type of self-consumption schemes and discusses the benefits and barriers for implementing in each type of self-consumption schemes.

5.1.2.1 Self-consumption scheme (pilot project) with no buyback

Basically, traditional households use electricity from the grid only and typically they do not produce electricity for their own use. So electromechanical meter or (spinning disc) for measuring electricity flow in one direction suffices for this purpose. Thailand's self-consumption scheme encouraged the installation of rooftop PV system for self-consumption with the aims of eventually introducing support scheme to compensate for exported electricity. Under this scheme, all prosumers must change their electromechanical to digital meters, which the utilities will use to monitor reverse power flow to the grid. The meter fee and meter monitoring fee were waived for all participants that are connected on the low voltage level (<12 kV) as given in Table 5.1. Nevertheless, higher voltage connection (> 12 kV) as given in Table 5.2, participants had to pay for meter and meter monitoring fee about 100,000 THB (DEDE, 2016).The benefit of using digital meter for this scheme is that utilities can monitor how much the excess generation flow back to the grid more accurate in order to prevent the negative impacts such as overvoltage to distribution networks, especially if penetration of PV is high in the future. Furthermore, utilities will be able to forecast the amount of excess generation to the distribution grid and can set the capacity cap more precisely. For prosumers side, they can upgrade their meter use with no cost; however, they might have to learn how to read the meter so that they will be able to monitor their own produced PV electricity. The barrier of this scheme is that someone, either the customer or the utility, must to bear the cost of meter.

Table 5.1: residential (electricity users type 1)

List	**Charge (THB)**
Meter fee	Responsible by distribution utilities

Table 5.2: Commercial sector (electricity users type 2-6)

List	**Voltage level**	
	Below 12 kV	12 kV or above
Meter fee	Responsible by distribution utilities	100,000 THB (*)

Noted: (*) not include value added tax (7%)

5.1.2.2 Net metering with rolling credit and buy back

Net metering requires the use of bi-directional (i.e. one register) meters. Bi-directional meters record the flow of electricity in both directions for energy consumption and energy production (Firstenergycorp, 2016). Electromechanical meters can serve this purpose since they allow electricity flow in and flow out as shown in Table 5.3. The benefit of this scheme is that prosumers do not need to change the meter; they can still use their existing electromechanical meter after rooftop PV systems are installed. As mentioned earlier, the mechanism of net metering with rolling and buyback scheme allows electricity flow in and flow out in the same direction. This means that when there is excess part of electricity from the rooftop PV system, which is injected back to the grid, the meter will spin in backwards and that part excess generation will be recorded as credits to be used to offset consumption in the next bills. However, the barrier of this type of meter would be on utilities since they cannot monitor reverse power flow to the grid and cannot collect their taxes. In addition, they have to set up a new accounting method for monitoring the energy consumed and the excess electricity to be credited toward the next billing period.

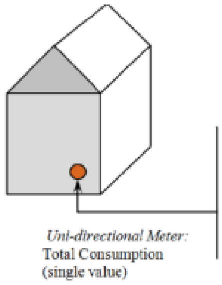
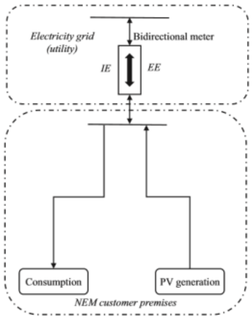
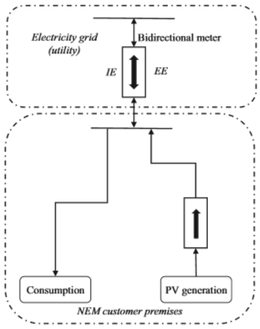
5.1.2.3 Net billing with real-time buyback (no rolling credit)

Net billing with real-time buyback (no rolling credit) requires two registers in order to monitor separately for net consumption and net production because they are treated at different rates. The mechanism of this scheme involves real-time or hourly valuation of excess generation. The type of meter used can be digital meters or smart meters for monitoring the energy consumption and excess generation that flow back into the grid in real-time (hourly) valuation. In this analysis, this research advises smart meter as the type to be used for this scheme. Since net billing with real-time buyback scheme involves hourly valuation of excess generation and has different time-based rates. For each hour that PV electricity produced more than the load and that excess part of electricity fed back to the grid, utilities will be able to monitor faster and gain more accurate data so that they can calculate billing more efficiently. In addition, using smart meter can be beneficial in various ways such as the ability to register real-time energy consumption, including voltage, current active, phase angle, and frequency measures as well as measure kWh, reactive power, load profile etc. (Rodriguez-Calvo et al., 2017; Sharma et al., 2015). Smart meter allows prosumers to monitor their energy usage and energy costs in real-time data so that they can optimize their energy consumption and reduce their electricity billing. In addition, for consumers who subscribe in TOU rate, especially commercial and industrial prosumers, since they pay different prices of electricity depending on time of the day. Using smart meter, they have the opportunity to reduce their electricity demand during peak times and potentially save more money on their electricity billing. For benefits of smart meter to utilities, smart meter enable utilities to monitor customer's electricity usage in hourly increments. Barriers of smart meters include challenges and costs to utilities, which may be related to long term financial commitment to procure new smart meter technology and related software. In addition, if the buyback rate is varied by the hour, utilities need to set up the meter to have hourly time stamp and require a different method for data collection (Tongsopit, 2015; Tongsopit et al., 2017)

The discussion and summary of meter in each type of self-consumption is demonstrated in Table 5.3.

Table 5.3: Summary of electricity meter in each type of self-consumption scheme. Adapted from Report on Rooftop PV Pilot Project Evaluation (Tongsopit et al., 2017)

Schemes	**Self-consumption**	**Net-metering with rolling credit and buy back**	**Net billing with real-time buyback**
Number of registers	1	1	2
Working principle	Unidirectional meter to record total consumption only	Bidirectional meter (one register)	Bidirectional meter (two register) to record both net consumption and net production

Schemes	**Self-consumption**	**Net-metering with rolling credit and buy back**	**Net billing with real-time buyback**
Type of meter	 Eid et,al,2014	 (Nikolaidis et al., 2017)	 (Nikolaidis et al., 2017)
Metering setting	Have to change to digital meter, utilities will be able to monitor excess electricity flow back to the grid.	No need to set meter, electromechanical meter allows electricity flow reversely.	Smart meter enable utilities to monitor customer’s electricity usage in hourly increments. Prosumer enable monitor their energy usage and energy costs in real-time data.
Example of meter uses	Digital meter 	Electromechanical meter 	Smart meter 

In conclusion, currently utilities supported new meters for residential PV prosumers and commercial PV prosumer (below 12 kV voltage connections) in Thailand self-consumption scheme in 2017. If prosumers have to bear cost of meter, their IRR may decrease and payback period would higher due to high cost of meter, consequently, this could result in less motivation to install rooftop PV system. Conversely, if utilities have to bear the costs of new meters, which will be higher at high PV penetration, utilities need to balance their financial commitment and mitigate the burden cost that might occurred in the future.

5.2 Grid code of rooftop solar PV installation

Distributed photovoltaic system in Thailand have been promoted by the government since 2013 through supportive policies such as the adder scheme, FiT scheme and compensation mechanisms (such as net metering, net billing). Although, solar PV systems provide the benefit of power generation capacity, high solar PV penetration could cause reverse power flow and cause over-voltage incidents that more likely to occur on low voltage (LV) networks, especially at the end of feeders (Huang et al., 2013; Pachanapan et al.). This situation could happen when the PV production is high during the light load condition, which impact to grid system for utilities in terms of voltage level. Hence, distribution utilities need to specify technical measures to prevent the impact of voltage level from high PV penetration, which require PV system to deal with power factor control at Point of Common Coupling (PCC). This method is specified in current grid connection code of MEA and Grid connection code of PEA 2016.

This section analyzes the current grid connection code of MEA and PEA for rooftop solar PV installation in Thailand by evaluating three aspects: grid connection code of utilities, inverter requirements and analysis of supports and barriers from current grid connection code for solar PV installation in Thailand. This research use grid connection code of MEA 2017 as the main grid code analysis.

In this regards, this section is mainly classified into three main parts as following:

(1). Grid connection code of distribution utilities

(2). Inverter requirements

(3).Analysis of supports and barriers from current grid connection code for solar PV installation in Thailand.

5.2 Grid connection code of distribution utilities

Distribution utilities regulate grid connection system for power generation through the 2559 Grid Code and specify the minimum technical requirement in terms of design system criteria and installation standard to be met by PV generators who wish to connect to the system and the procedures to be followed to ensure compliance with these conditions. The main objectives are to ensure:

(1). To have an appropriate methods of interconnection between applicants and grid system and set as the basis for interconnection.

(2). To set clearly regulations by containing the minimum technical design for applicants and include the technical details of electrical equipment and point of common coupling standard.

(3). To ensure the power quality for general users in the standard of MEA after having connected to grid system.

(4). To operate the generator that connect to grid system of MEA and ensure the effectiveness and safety between interconnection and grid system.

This research focuses on Very Small Power Producer (VSPPS) by considering the points as follows:

5.1.2.4 VSPP Installed capacity of solar PV system

Very Small Power Producer (VSPP) is power suppliers that sell electricity to MEA with installed capacity of PV system less than 10 MW (Krungsri, 2016) and typically interconnect between low voltages (LV) to medium voltage (MV) as follows:

(1). Low voltage at 230/400 kV – (Phase and line voltage)

VSPP can interconnect to a single-phase and three-phase to power distribution system. For single-phase, installed capacity must not exceed 5 kilowatts. For three-phase, power generation can be supplied by allowing the installed capacity have the difference between phases must not exceed 5 kilowatts.

In addition, the total installed capacity (kW) of PV system that interconnects to grid system must not exceed 15% of transformer rating (MV/LV Transformer).

(2). Medium voltage at 12 and 24 kV

VSPP can connect and supply electricity to the grid system, if the total installed capacity per transmission line must not exceed 4 kilowatts at 12 kV.

VSPP can connect and supply electricity to the grid system, if the total installed capacity per transmission line must not exceed 8 kilowatts at 24 kV.

In addition, the total installed capacity (MW) of PV system that interconnects to grid system must not exceed 20% of transformer rating (MV/LV Transformer).

Table 5.4: Different voltage level of Thailand's distribution utilities

Distribution utilities	Voltage levels	
	Medium Voltage (MV)	Low voltage (LV)
MEA	12 kV	1 phase 230 v
	24 kV	3 phase 400 v
PEA	22 kV	1 phase 220 v
	33 kV	3 phase 380 v

Source: MEA, 2016

5.1.2.5 Voltage regulation at Point of Common Coupling: PCC

Grid operator specifies that VSPP who wish to connect PV system to the grid system must control voltage at connection point in accordance with the range between maximum and minimum voltage. The control voltage level must be controlled for both case of PV system supply/not supply electricity to the distribution grid system. The control voltage level is classified into two conditions: normal condition and urgent condition as given in Table 5.5 and 5.6.

Table 5.5: Maximum and minimum voltage regulation of MEA, in the case of generators **do not supply electricity** to distribution grid.

Voltage level	**Normal condition**		**Urgent condition**	
	Max	**Min**	**Max**	**Min**
24 kV	23.6	21.8	24	21.6
12 kV	11.	10.9	12.0	10.8
400 kV	410	371	416	362
230 kV	237	214	240	209

Source: (MEA, 2016)

Table 5.6: Maximum and minimum voltage regulation of MEA, in the case of generators **supply electricity** to distribution grid.

Voltage level	**Normal condition**		**Urgent condition**	
	Max	**Min**	**Max**	**Min**
24 kV	23.6	21.8	24	21.6
12 kV	11.8	10.9	12.0	10.8
400 kV	410	371	416	362
230 kV	237	214	240	209

Source: (MEA, 2016)

Maintaining voltage ranges is critical to avoid damaging customer and utility equipment.

Based on the review from grid codes of distribution utilities, it is summarized in Table 5.10 for PV system size in each voltage level.

Table 5.7: Summary of grid integration rule of rooftop PV system installation

Generator type	Voltage level of distribution grid			
	24 kV	**12 kV**	**230/400 V For 1 phase**	**230/400 V Multi 1 phase connections**
VSPP (Solar PV rooftop)	Not exceed 8 MW / feeder	Not exceed 4 MW/ feeder	Not exceed 5 kW/ phase	-
	Not exceed 20% of transformer			The difference between phase < 5 kW
			Not more than 15% of transformer, If exceed 15%, applicator can connect at 12 or 24 kV and must install distribution transformer with protective equipment in accordance with utilities standards.	

Source: Adapted from (Surachai Chaitusaney et al., 2017)

5.3 Grid-tied inverter requirement

Grid-tied inverters play an important role in generating power by PV panel, which is directly fed to the transmission grid and it is distributed. Understanding grid code requirement is essential in grid-tied inverter because it works in parallel with the grid. Fundamentally, the main function of grid-tied inverter is to convert DC (Direct current) power produced by PV panels to AC (Alternative current) power to supply to electrical appliances and sell excess generation back to the distribution grid (Algaddafi et al., 2017; Arulkumar et al., 2016; Huang et al., 2013; Teodorescu et al., 2011). Basically, there are three different criteria of control functions for all grid-connected inverters as given in Table 5.8.

Table 5.8: The example of common control structures for all grid-connected inverter

Control structures	**Elements**
1. Basic functions	Grid current control ○ THD limits imposed by standards ○ Stability in the case of large grid impedance variations ○ Ride-through grid voltage disturbances DC Voltage control ○ Adaptation to grid voltage variations ○ Ride-through grid voltage disturbances Grid synchronization ○ Operation at the unity power factor as required by standards ○ Ride-through grid voltage disturbances
2. PV Specific functions	Maximum power point tracking (MPPT) ○ Very high MPPT efficiency during steady state (typically > 99 %) ○ Fast tracking during rapid irradiation changes (dynamical MPPT efficiency) ○ Stable operation at very low irradiation levels Anti-islanding (AI), as required by standards (VDE 0126, IEEE 1574, etc.) Grid monitoring ○ Synchronization ○ Fast voltage/frequency detection for passive AI Plant monitoring ○ Diagnostic of PV panel array ○ Partial shading detection
3. Ancillary functions	Grid support ○ Local voltage control ○ Q compensation ○ Harmonic compensation ○ Fault ride-through

Source: (Teodorescu et al., 2011)

According to Thailand grid code requirement in 2016, grid-tied inverters must be qualified and tested in accordance with the requirement for the grid-tied inverter used in the grid-connected power generation system so that generator will be allowed to connect to the distribution grid system. Since grid-tied PV can cause overvoltage due to allowing PV electricity flow back to the grid. Thus, grid-tied inverter that connect to the distribution grid system must control the voltage operating range in case of blackout situation in order to prevent harming to any line workers as follows:

(1). Grid-tied inverter connected low voltage level (230/400 v)

Grid-tied inverters must quickly disconnect the circuit at the point of common coupling (PCC) before the maximum disconnect time in accordance with Table 5.8.

Table 5.9 : The range of voltage level and maximum disconnect time of grid-connected inverter at voltage level (230/400 V)

The range of voltage operating(Volt)		**Maximum disconnect time (Second)**
Line voltage	**Phase voltage**	
V < 199	V < 115	0.1
199 ≤ V ≤ 346	115 ≤ V ≤ 200	2.0
346 ≤ V ≤ 416	200 ≤ V ≤ 240	Continuously operating (no disconnect)
416 ≤ V ≤ 539	240 ≤ V ≤ 311	2.0
V ≥ 539	V ≥ 311	0.05

(2). Grid-connected inverter connected at voltage level up to 12 kV

Grid-connected inverters must quickly disconnect the circuit at the connection point before the maximum disconnect time in accordance with Table 5.9.

Table 5.10: The range of voltage level and maximum disconnect time of grid-connected inverter at voltage level up to 12 kV

The range of voltage operating (Volt) (% of nominal voltage of inverter)	**Maximum disconnect time (Second)**
V < 50%	0.1
50 % ≤ V ≤ 85%	2.0
85% ≤ V ≤ 110%	Continuously operating (no disconnect)
110% ≤ V ≤ 135%	2.0
V ≥ 135%	0.05

These two tables presents the voltage range of low voltage level (230/400 v) and at voltage level up to 12 kV. Since, Thailand has just started the self-consumption policy, allowing the excess generation to flow back into the grid by which no buyback for that part of the injected electricity. Utilities has verified the new list of grid-tied inverters for both MEA and PEA areas for more safety and protect the damage to the feeder system of distribution grid. As given in table 5.11, Table 5.12, and Table 5.13 are grid-tied inverter approval list for connected to distribution network by MEA, PEA, respectively.

Table 5.11: Example of Grid-tied inverter approval list, verified by MEA grid code requirement from 194 in total.

(Information as of 9 October 2017)

No	**Brand**	**Model/type**	**Description**
1	ABB	PVI-3.6-TL-OUTD	230 V, 1ph, 50 Hz, 3.6 kW
		PVI-5000-TL-OUTD	230 V, 1ph, 50 Hz, 5 kW
		PVI-10.0-TL-OUTD	400 V, 3ph, 50 Hz, 10 kW
6	FRECON	F010i-4PVb	400 V, 3ph, 50 Hz, 10 kVA
7	Growatt	Growatt 3600 MTL-10	220 V, 1ph, 50 Hz, 3.6 kVA
8		Growatt 5000 MTL-10	220 V, 1ph, 50 Hz, 4.6 kVA
9	Huawei	SUN2000-12KTL	230/400 V, 3ph, 50 Hz, 12 kVA
10		SUN2000-20KTL	230/400 V, 3ph, 50 Hz, 20 kV
11		SUN2000-33KTL	400 V, 3ph, 50 Hz, 30 kVA
13	JFY	SUNTWINS 5000TL	230 V, 1ph, 50 Hz, 5 kW
14		SUNTREE 10000TL	230/400 V, 3ph, 50 Hz, 10 kW
15		SUNTREE 30000TL	230/400 V, 3ph, 50 Hz, 30 kW
16	Primevolt	PV-3000N-V	230 V, 1ph, 50 Hz, 3 kVA
18		Conext RL 5000 E	230 V, 1ph, 50 Hz, 5 kVA
19	SMA		230 V, 1ph, 50 Hz, 3.68 kW
20		SB 5000TL-21	230 V, 1ph, 50 Hz, 5 kW
21		STP 25000TL-30	400 V, 3ph, 50 Hz, 25 kW
22	Solar Edge	SE5000	230 V, 1ph, 50 Hz, 5 kW
23	Trannergy	TRI017KTL	230/400 V, 3ph, 50 Hz, 17 kW

Source: (MEA, 2017b)

Table 5.12: Example of Grid-tied inverter approval list, verified by PEA grid code requirement for total installed capacity not more than 500 kW
(Information as of 16 June 2017)

No	**Brand**	**Model/type**	**Rated power**	**AC Voltage rated**
1	Leonics	Apollo S-219C	5	1ph, 220 V
		Apollo MTP-624F ia	30	3ph, 220/380 V
		Apollo GTP-4010TLP	10	3ph, 220/380 V
		Apollo GTP-4020TLP	20	3ph, 220/380 V
2	Gravic	G-4300TLS	3	1ph, 220 V
		G-4300TLD	5	1ph, 220 V
3	SMA	SB 9000TL-30	9	3ph, 220/380 V
		SBS sb5.0-1av-40	5	3ph, 220/380 V
4	Chuphotic	Sun SGS-20si	20	1ph, 220 V
		Sun SGS-50si	50	1ph, 220 V

Source: (PEA, 2017)

Table 5.13: Example of Grid-tied inverter approval list, verified by PEA grid code requirement for all PV system sizing.
(Information as of 16 June 2017)

No	**Brand**	**Model/type**	**Rated power**	**AC Voltage rated**
1	Kaco	Blueplanet 6.5 TL3 M2	680 kW	3ph, 380 V
		Blueplanet 7.5 TL3 M2	6.5 kW	3ph, 220/380 V
		Blueplanet 9 TL3 M2	7.5 kW	3ph, 220/380 V
2	SMA	STP 25000TL-30	25 kW	3ph, 220/380 V
3	Frecon	F010i-4PVb	10 kVa	3ph, 220/380 V

Source: (PEA, 2017)

Based on the approval list of grid-tied inverters for MEA and PEA, it can be noticed that MEA's grid tied-inverter list has more approved inverter products than PEA list. This can be due to the different distribution network system between these two areas. The grid-tied inverters approval list can help generators to feel free to choose variety brands of inverter and more importantly, can protect utility worker due to the occurrence of abnormal connection.

5.4 Analysis of the supports and barriers of current grid code for rooftop solar PV installation in Thailand

This section analyses the supports and barriers of current grid code for solar PV installation under the current Thailand's self-consumption scheme as follows:

5.4.1 Limitation of PV sizing

The main issue of Thailand's self-consumption pilot scheme is the prevention of reverse power flow of excess electricity from PV system in order to avoid overvoltage especially in low voltage connection. This impact may cause the limitation of PV sizing in each voltage level and the transformer cap as given in Table 5.10. However, this current pilot project already waived the installation of reverse power device for low voltage connection if total installed capacity does not exceed 15% of the transformer capacity. For higher voltage connection, directional power relay (32R) must be installed to prohibit reverse power flow of excess electricity to the distribution grid. This might be the main barrier for commercial customers who want to maximize their rooftop PV system in order to match their load.

The limitation of PV sizing in each voltage level might cause a low uptake of rooftop solar PV systems. For example, the Grid Code specifies that for single phase user s(typically residential households) connected to the low voltage, the installed capacity of each PV system was limited to a maximum of 5 kW. This number could be a limitation to the prosumer who want to install more than 5 kW. Regarding to the 15% of transformer cap, it was considered as major technical issue to limit sizing in local network. This number was relatively a small number. Depending on how much of PV already installed in local networks, once the certain level of PV already exists on local network i.e. the total 15% transformer cap was reached. Then, the new PV systems would be prohibited in that area. Otherwise, the new PV systems have to install reverse power relay or install PV system outside pilot project.

5.4.2 Additional investment from reverser power relay

In regard to the 15% of transmission cap, it caused an additional investment of reverse power relay installation in order to avoid voltage rise. This number was relatively small and limited PV system sizing because this number cannot reflect the reasonableness of the installed capacity of rooftop PV system into the distribution grid that may impact to the distribution grid. As mentioned above, Thailand's self-consumption scheme allowed the reverse power flow electricity to the grid and waived for the installation of reverse power relay if the total installed capacity do not exceed the transformer cap. If exceed the transformer cap, generators have to connect at 12 or 24 kV and must installed distribution transformer with protective equipment in accordance with grid code standards. Most of the protective equipment is expensive with the price approximately 100,000 THB. This requirement can be obstructed the installation of PV system especially for larger PV system.

In addition, the percentage of transmission cap should be revised and more flexible in order to reduce the burden of capital cost for generators and increase penetration of rooftop solar PV system in the future

5.4.3Grid-tied inverter requirement

Grid-tied inverters play a key role in rooftop solar PV system and typically work in parallel with the distribution grid. It is important that inverter technology must have reliable and safety function for grid interconnection operation of PV system. Traditionally, power system is designed as a unidirectional transmission system by supplying electricity to customers. However, since Thailand has made the transition from subsidized solar PV policy to self-consumption policy, which allow the excess power flow reverse to the power grid and may cause the unacceptable voltage at the point of common coupling. The drawback of voltage rise may result in power loss in power transmission line and power devices. In addition, it may decrease the power quality of the generation system, and limit the penetration ration of PV system in grid system (Huang et al. (2013).

According to the grid-tied inverter requirements as mentioned earlier, this research discusses the support and barriers as follows:

(1). Support function of grid-tied inverter requirements

- *Voltage regulation*

  Grid-tied inverter must match the phase of the grid and maintain the output voltage according to the voltage regulation at any instant. In case of overvoltage, inverter must automatically stop supplying electricity to the power lines when the grid is down. In addition, grid-tied inverter has the function to control and prevent reverse power flow that can work equivalent to directional power relay. For the large PV installation, this could save the cost by installing only grid-tied inverter without additional directional power relay requirement.

- *Frequency*

  When the grid goes down, the anti-islanding feature on the grid tie inverter will realize that either there was a sudden change in system frequency, voltage, rate change of frequency. In the event of a grid failure, it is possible that the PV inverter could continue to supply power and energize nearby loads. This is called "islanding". Anti-islanding is a feature of a grid-tied inverter that senses when there is a power outage and shuts itself down and stops the production of electricity. Thus, grid-tied inverter shuts down PV system and no longer produces and supply electricity to the grid for the safety of utility staffs who repairing the grid.

(2). Barrier The limitation from grid-tied inverter requirements

When the grid experiences a power outage, household or building grid-tie inverter cannot function. Hence, PV system cannot generate electricity at that time. If under net metering or net billing scheme, prosumers may lose their PV electricity at that time and loss the opportunity to maximize their excess generation to the grid.

In conclusion, currently utilities supported new meters for residential PV prosumers and commercial PV prosumer (below 12 kV voltage connections) in Thailand self-consumption scheme in 2017. However, regard to current grid code requirement, there are two hindrances according to technical requirements, including the limitation of PV system sizing in each voltage level and additional requirement of reverse power relay due to the limitation of transformer cap. Since, Thailand has just started the self-consumption policy, allowing the excess generation to flow back into the grid by which no buyback for that part of the injected electricity. Technically, allowing PV electricity flow back to the grid can cause overvoltage from rooftop solar PV system that connected to the distribution network system. In order to prevent this situation, both MEA and PEA have revised the new grid-tied inverter approval list in accordance with grid code requirement in order to avoid the damage to the feeder system of distribution grid when blackout incident occurs. The new grid-tied inverter approval lists ensure safely and stability with the support functions in accordance with the grid code requirement.

CHAPTER 6
STAKERHOLDERS' PERSPETIVES RESULT AND DISCUSSION

This chapter investigates the perspectives of stakeholders on the detailed design options of self-consumption schemes for supporting rooftop solar PV systems installation. The groups of stakeholders include consumers, private companies, policymakers, and distribution utilities. The research methodology employed questionnaires and in-depth interviews in order to understand all study related stakeholders' perspectives on each element of rooftop solar PV self-consumption schemes. The results are classified into two main parts: self-consumption scheme design and excess generation scheme design. The most of stakeholder groups indicated a strong desire to compensate for excess generation from rooftop solar PV systems in order to encourage Thai consumers to invest rooftop PV systems and also to accelerate market expansion.

6.1 Stakeholder Respondents Group

Table 6.1 shows the number of respondents and category by group. The total numbers of respondents from four workshops are 72. Most of stakeholders in this survey were directly involved in rooftop solar PV policy development or market development in Thailand. The surveys were conducted between September and December 2016. The gathered feedback was the basis of the results and discussions of this research.

Table 6.1: Survey respondents

	Consumers	Private companies	Policymakers	Utility (MEA)	Utility (PEA)	Total
Stakeholder engaged	13	21	9	16	13	72

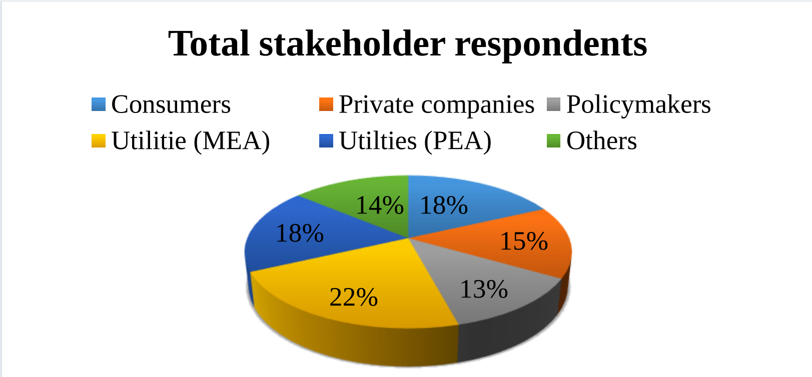
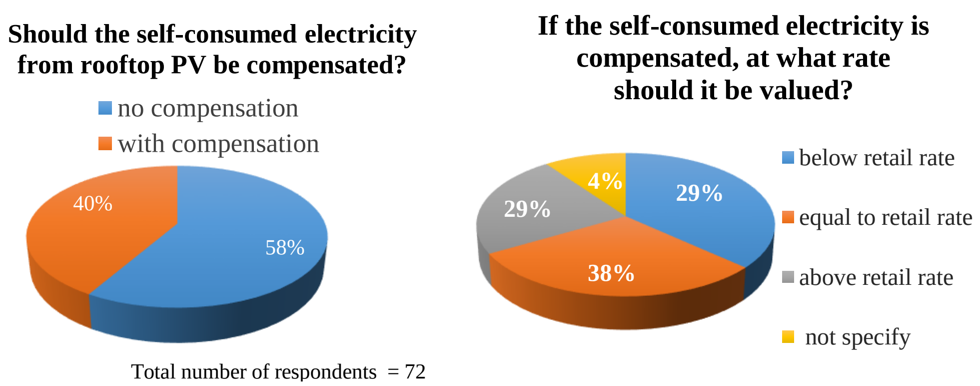


Figure 6.1: Summary of total stakeholder's respondents

6.2 Self-consumption Scheme Design

Figure 6.2 represents the result of self-consumed electricity scheme, which shows that the majority of respondents (58%) selected no compensation for the self-consumed part of PV electricity, whereas 42% of respondents preferred PV self-consumption to be compensated. The finding shows that most of stakeholders preferred no compensation for the self-consumed part of electricity. This preference corresponds to the design of most self-consumption schemes worldwide, which do not compensate for the self-consumed part of electricity.

When classifying the types of stakeholders in order to understand the responses from each stakeholder groups, the study founded that the most of the respondents who represented the PEA and consumer groups preferred to give compensation to the self-consumed part of electricity. The majority of members from other groups preferred not to have compensation for excess electricity.



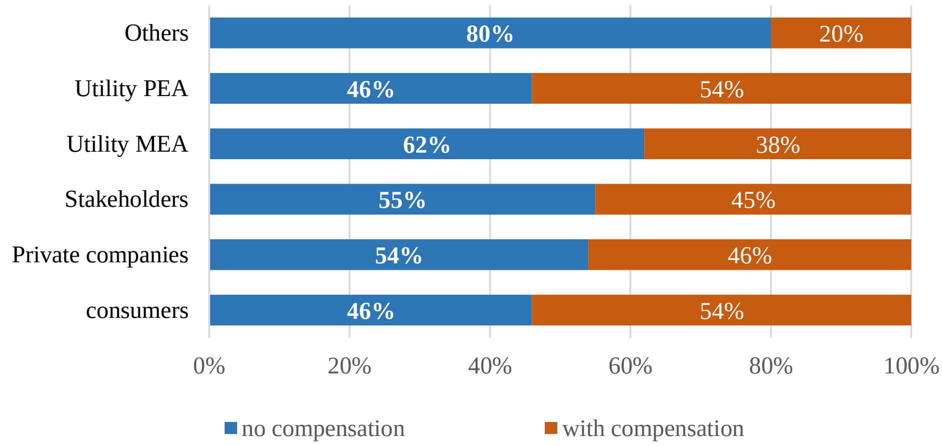
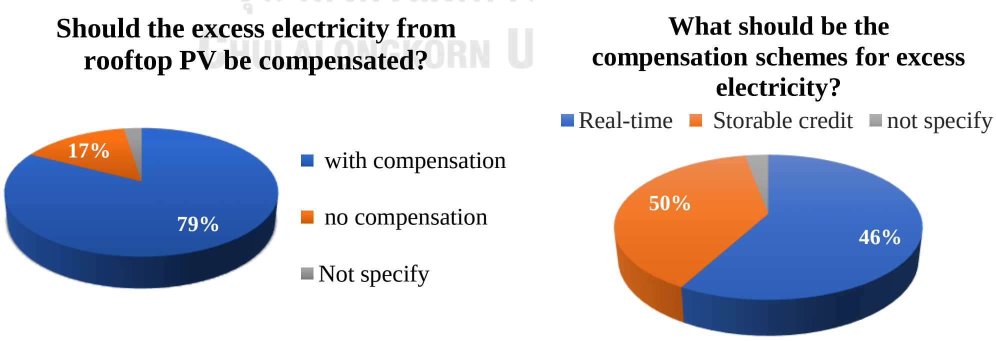


Figure 6.2: The result of self-consumption scheme design from all stakeholders.

6.3 Excess Generation Scheme Design

Figure 6.3 shows that the majority of respondents (79%) preferred to gain compensation for the excess part of electricity from rooftop PV systems. For those that chose to have compensation for excess electricity, the study asked whether the compensation should be in the form of collected credits or whether the compensation should occur as real-time payment. Most of respondents were split equally between these two types of the compensation schemes for excess part of PV electricity.



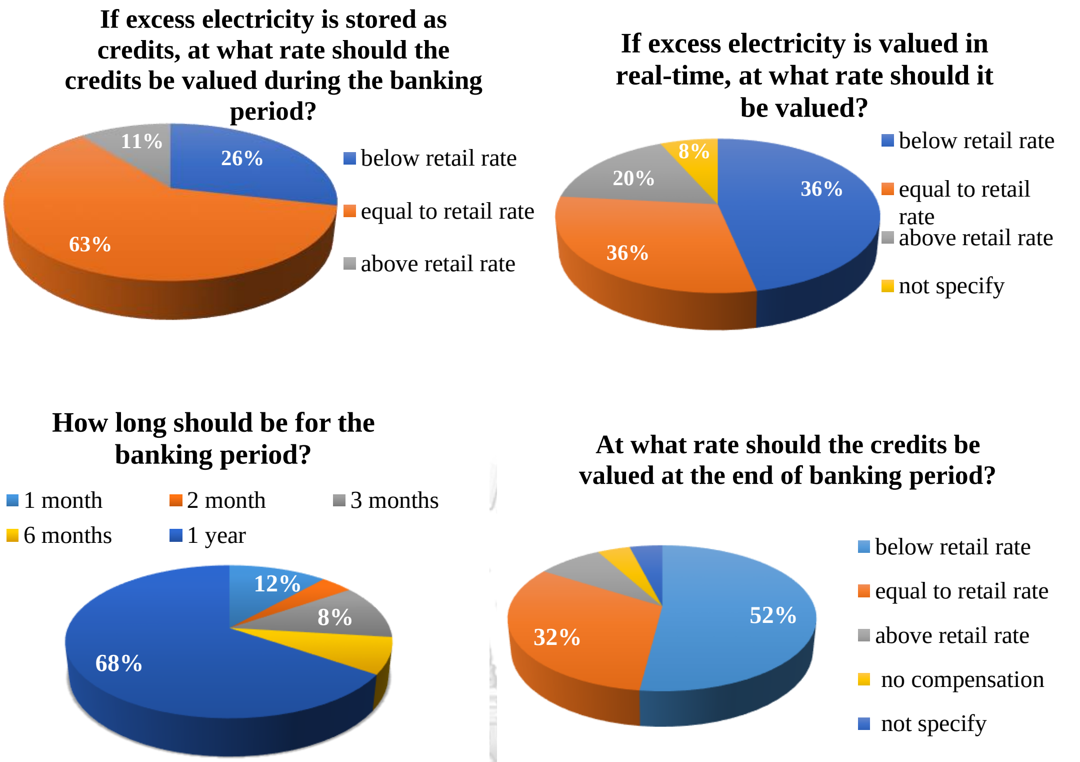
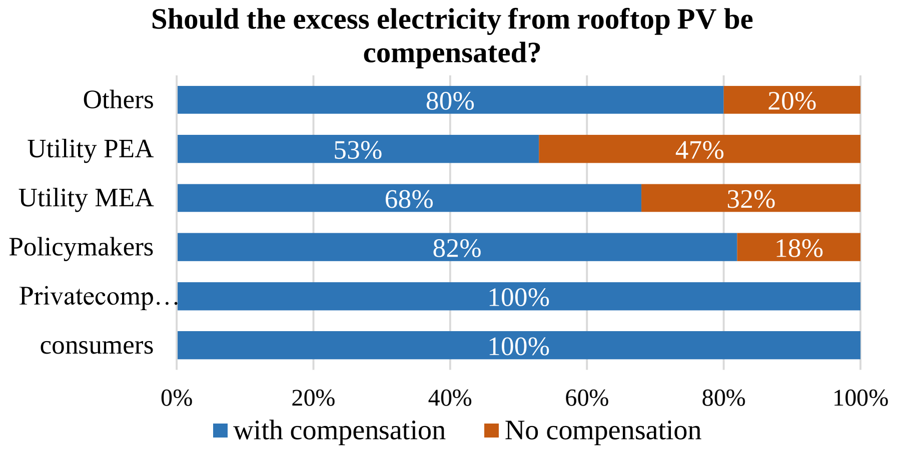
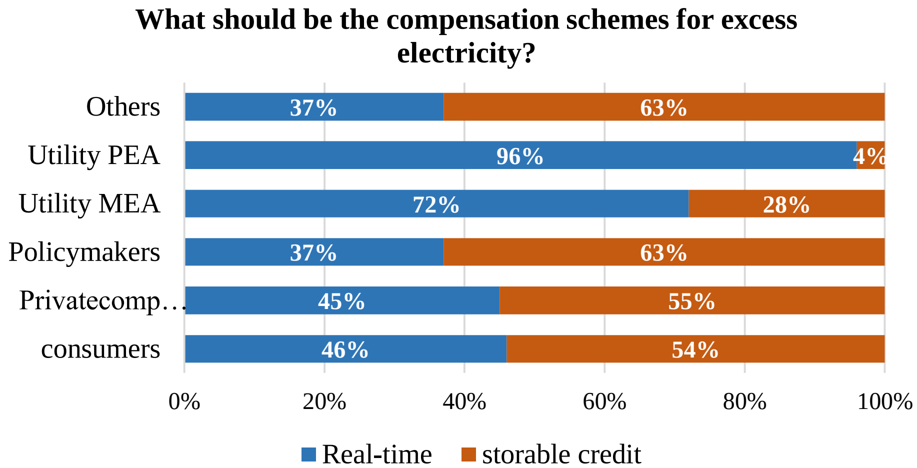
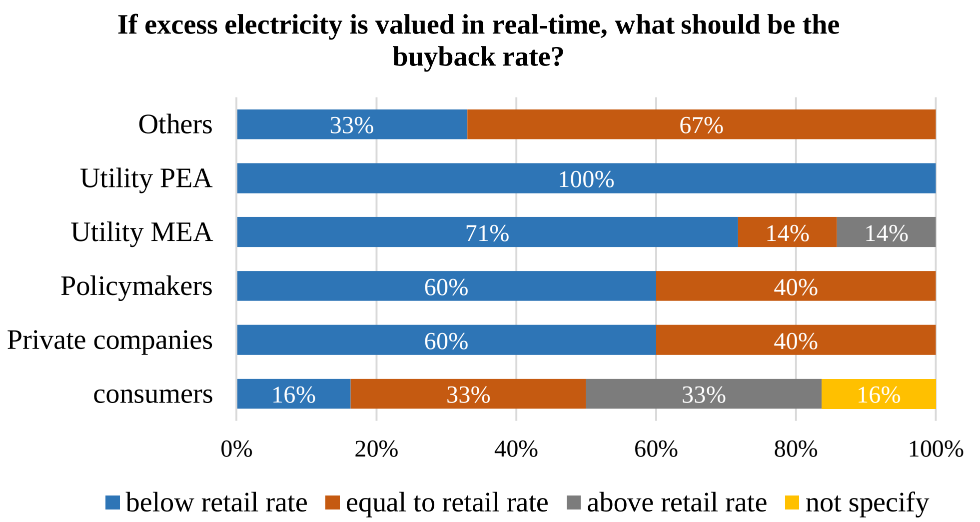


Figure 6.3: The result of excess generation scheme design from all stakeholders

Among those who chosen to have excess generation compensated in the form of credits, 63% of them specified that the value of credits should be equal to retail rate. For real-time compensation, the study asked what the real-time buy-back rate should be. Most of the respondents were split equally between below retail rate and equal to retail rate, which is very interesting. The study also asked regarding the cap for compensation per year and most of respondent agreed to define a capacity cap per kWh/person/year. Based on the overall result from all stakeholders, the findings identified differences in opinions and preferences among consumers, private sectors, policymakers and utilities as shown in Figure 6.4. It is clearly indicated that the majority of utilities preferred real-time payment as compensation method


Should the excess electricity from rooftop PV be compensated?
Others
Utility PEA
Utility MEA
Policymakers
Privatecomp…
consumers
80%
20%
53%
47%
68%
32%
82%
18%
100%
100%
0%
20%
40%
60%
80%
100%
with compensation
No compensation


What should be the compensation schemes for excess electricity?
Others
Utility PEA
Utility MEA
Policymakers
Privatecomp…
consumers
37%
63%
96%
4%
72%
28%
37%
63%
45%
55%
46%
54%
0%
20%
40%
60%
80%
100%
Real-time
storable credit


If excess electricity is valued in real-time, what should be the buyback rate?
Others
Utility PEA
Utility MEA
Policymakers
Private companies
consumers
33%
67%
100%
71%
14%
14%
60%
40%
60%
40%
16%
33%
33%
16%
0%
20%
40%
60%
80%
100%
below retail rate
equal to retail rate
above retail rate
not specify

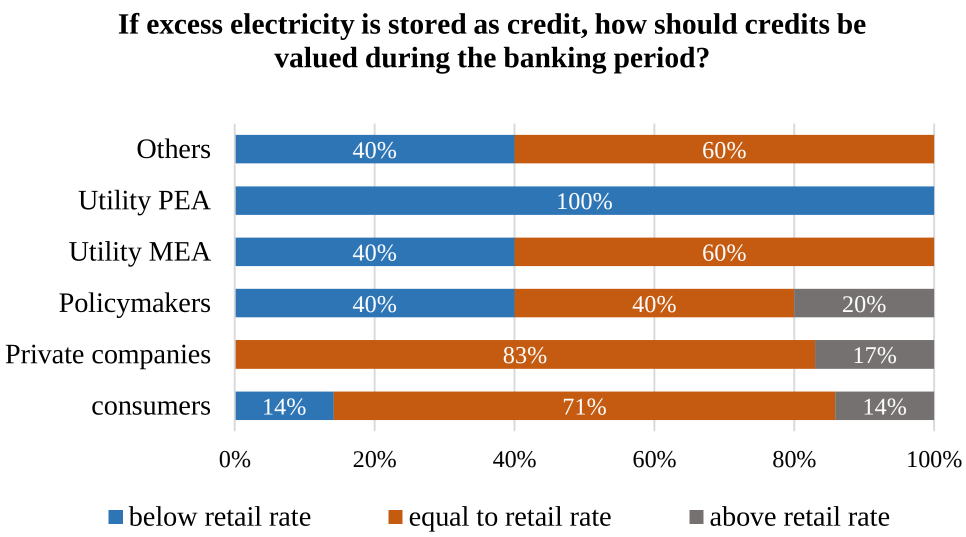


Figure 6.4: The result of excess generation scheme design, classified by each stakeholder.

For excess PV generation with the rate valued at the price below retail rate, it is called net billing. Whereas most of stakeholders agreed that the excess part of electricity should be collected in credits within one year period and the rate of that part should be valued at the price equal to retail rate. This may be due to the scheme seemed to be more attractive especially to consumer and private companies and could stimulate the market expansion. This selected scheme design is called net metering with rolling credit and with buyback. In term of compensation, the benefit of net metering scheme is that the electricity that self-consumed and flow back into the grid is allowed for the compensation at retail rate, which is very attractive to consumers. However, this compensation may result in faster and higher in revenue losses to the utilities if there is higher distributed solar photovoltaic penetration.

For net billing, the rate of excess electricity can be valued at below, equal, or higher than retail rate, depending on the market condition. It may depend on the most of the power that generated from the rooftop PV system and consumed power that generated from the rooftop PV system and consumed, even the buy-back rate is low, and it might stimulate the market. However, the key point is that the rate of excess electricity requires certain justification and it needs to be updated on regular basis (e.g. yearly). The reasons why utilities seem to prefer net billing than net metering are due to considerations in term of accounting set-up and taxes. Net billing accounting set up would be easier meanwhile net metering may require setting up new accounting system for excess generation that will flow back into the grid in the current month, which is credited into the subsequent bill. In term of taxes, since net billing requires two meters for monitoring the electricity that consumed from grid and excess part of PV electricity that flow back into the grid separately, Utilities can collect taxes from excess electricity that purchased, whereas the taxes revenue can be lose from the compensated credits. Additionally, considering the meter system, net metering requires only one meter, which residential consumers no need to change for a new meter, they still can use their existing electromechanical meter because this type of meter allow the electricity run backward. Unlike net billing, the higher cost can occur to utilities for providing new meters; besides, net billing need to set up the new meter with hourly time stamp and requires more memory on the meters and the needs to recruit more staff in order to read different metering data.

In conclusion, based on the results through survey questionnaire, all stakeholder groups selected no compensation for self-consumed part of electricity as shown in Table 6.2. For excess part of PV generation, all stakeholder groups preferred excess part of PV generation can be banked as credits, except utilities that preferred real-time valuation. The reason behind each stakeholder groups on each preferred design option will be discussed in the next section together with the pros and cons of net metering and net billing schemes.

Table 6.2: Summary of all selected schemes from each stakeholder group

Stakeholder groups	Self-consumed electricity		Excess generation of electricity	
	No compensation	With compensation	Bank as credits	Real-time payment
Consumers	√		√	
Private companies	√		√	
Policymakers	√		√	
Utilities	√			√
Others	√		√	

6.4 **Analysis of the pros and cons of net metering and net billing.**

This section discusses the pros and cons of net metering and net billing based on perspectives from every stakeholder group. This analysis was based on the outcomes of detailed supporting scheme design through survey questionnaires. For self-consumption scheme, most of stakeholders satisfied with no compensation for self-consumed part of PV electricity. The feedbacks suggested that the respondents believe this scheme is already profitable without adding premium tariff. Since self-consumed electricity is allowed and the prosumers are able to consume their own PV generation which is valued at retail rate, it will instantaneously reduce electricity bill. In term of compensation, consumer would prefer net metering mechanism because the excess generation is valued at retail rate, which is very attractive and highly encouraging for rooftop PV system installation. In addition, specifically for residential consumers, there is no need to pay for a new meter because the existing meter allowed the excess generation to run backward into distribution grid. As for private companies, which preferred net metering because this scheme does not require any payment during the year due to the excess of PV electricity is kept as a credits, which means no need to set quota. In addition, at the end of banking period, the left credits can be valued at zero. However, this scheme would impact utility company in term of revenue losses and increase burden in term of accounts and taxes. Both utility companies think net metering was not an option as it would require complex account setting and inability to collect tax.

These two issues would be the problems that prevent the net metering scheme to be implemented. In term of the rate, if excess generation valued at the full retail rate, utility companies might lose their revenues faster because they typically purchase electricity from the Electricity Generating Authority of Thailand (EGAT) at a wholesale rate. So, both utility companies would prefer net billing with real-time buyback but should not be hourly netting because it requires changes in digital meter setting to collect more data and also imply changing or further training of meter reading personnel towards a digital savvy and recent metering technology.

CHAPTER 7
CONCLUSIONS AND POLICY RECOMMENDATIONS

The objectives of this research are to find out the most feasible self-consumption schemes of rooftop solar PV adoption for residential and commercial sectors in Thailand and investigates the drivers and barriers that are associated with each type of self-consumption schemes. To supplement the understanding of the schemes, this research assessed the technical factors associated with each scheme and investigated the perspectives of stakeholders on each element of rooftop solar PV schemes in order to help with the design of future support rooftop solar PV policy in Thailand.

7.1 Conclusion of this research

In August 2016, Thailand implemented self-consumption scheme to promote rooftop PV system installation in the forms of net metering mechanism. This scheme was placed as a pilot project scheme in order to use this scheme to firstly evaluate data in terms of economic, technical and stakeholders' perspective towards the government in order to design for future support scheme for rooftop PV. However, rooftop PV installations totaled approximately 38 MW approved out of the quota of 100 MW, which was considered a low uptake for both residential and commercial sectors in Thailand. The contrast between self-consumption scheme and low deployment of rooftop PV system prompted this research to assess the economic feasibility of Thailand's self-consumption scheme together with compensation methods, including net metering and net billing.

As explained in the Chapter 1, this study was to address the following questions:

Question1: Are various self-consumption schemes feasible from the perspectives of residential and commercial rooftop owners?

According to the result of SAM modeling, all selected three self-consumption schemes are feasible from the perspectives of residential and commercial rooftop owners.

For residential block rate, comparing the feasibility results across three schemes, Thailand's self-consumption scheme, net metering with rolling credit and buyback, and net billing with real-time buyback, this research found that net metering with rolling credit and buyback is the most feasible scheme with the lowest payback period of 8.1 year, highest NPV value of 345,911 THB, and highest IRR of 13%. The justification of this scheme is that it allows prosumer can bank their excess electricity generation of PV electricity to keep as credit and roll over until the end of banking period.

For residential TOU rate, there are interesting findings between net metering with rolling credit and buyback scheme and net billing with real time buyback. Consider payback period criteria, net metering with rolling and buyback with three different rates, wholesale, retail, and premium rates are the most profitable scheme due to shortest payback period, while premium buyback rate yield the shortest payback period. However, net billing with real time buyback gives higher NPV values than net metering with rolling credit and buyback. This result is in contrast to the case of residential block rate.

For commercial TOU rate, comparing the feasibility results across the three schemes, the result shows that net metering scheme with rolling credit and buyback with wholesale, retail, and premium rates are the most feasible scheme for rooftop solar PV system. This scheme shows the highest NPV value of 1,546,495 THB with lowest payback period of 8.2 years, and IRR of 12%.

In addition, this research found that the initial investment of rooftop PV system is not a significance barrier to deployment rooftop PV system in Thailand. The main reason could be due to the falling cost of PV system from 60 THB/W in 2015 (Potisat et al., 2017) to 55 THB/W based on market price survey between May-June 2017.

Question 2: What are the technical factors that support or obstruct the implementation of each type of self-consumption schemes?

Based on the discussion in Chapter 5, the technical factor is classified into two categories: meter and grid code requirements.

For meter requirements, utilities supported for digital metering changing for residential PV system and commercial PV system that connect below 12 kV voltage connections for Thailand self-consumption scheme. Thus, they did not have to bear the cost of meter changing and can reduce their net capital cost. However, commercial sector who connect higher voltage connection (12 kV or above), they required to pay for the metering monitoring fee approximately 100,000 THB. This can be considered as kind blocking the implementation of current Thailand's self-consumption scheme.

For grid code requirement for PV installation, this research focuses on PV sizing in each voltage level, additional cost from additional protection devices and grid-tied inverter requirements as described below:

1. **PV system sizing**

   The hindrance of technical requirement based on this research analysis suggested the sizing of PV system is limited in each voltage level, which fewer uptakes for solar PV penetration. Since, Thailand's self-consumption scheme allowed the excess generation of PV electricity flow back to the distribution grid. The problem that may occurs reverse power flow of electricity is overvoltage. Thus, utilities limit for PV system size in each voltage connection in order to prevent the over reverse power to the grid. In addition, the transformer cap is limit at 15% for the total installed capacity. This number was considered as technical impact because this percentage is relative small and cannot reflect the reasonableness of the installation of rooftop PV system into the distribution grid.

2. **Reverse power relay**

   Another hindrance from technical requirement based on grid code analysis suggested additional requirement of reverse power relay causes additional investment cost for higher voltage connection. Despite, current self-consumption scheme waived for reverse power relay installation, higher voltage connection still required installing directional power relay, which may increase investment cost of PV installation. Consequently, a number of rooftop solar PV installations were low uptake in large PV installation systems.

3. **Grid-tied inverters**

   The new arrival list of grid-tied inverters for both MEA and PEA have support functions for ensuring the safety and reliability under Thailand's self-consumption scheme to the distribution network system. Since grid-tied PV can cause overvoltage due to allowing PV electricity flow back to the grid. The support functions of grid-tied inverter, including voltage regulation and frequency can maintain the output voltage and automatically disconnect the circuit at the connection point when blackout situation happens.

Questions 3: How do different stakeholders perceive various options on self-consumption schemes?

This analysis based on the outcome of detailed supporting scheme design through questionnaires. The survey asked stakeholder opinions about the consumed & excess part of the electricity. For self-consume part, PV generation that does not exceed electricity demand, most consumers of stakeholders satisfied with no compensation for self-consumed part of PV electricity. From the advantage to consumer was that self-consumed electricity was allowed and the prosumers were able to consume their own PV generation which was valued at retail rate, it would instantaneously reduce electricity bill. In term of compensation, consumer would prefer net metering mechanism because the excess generation is valued at retail rate, which is very attractive and encouraging for rooftop PV system adaptation. There were various distinct perspectives of utilities and private sector between net metering and net billing preferences. As for private companies, which preferred net metering because this scheme would not require any payment during the year due to the excess of PV electricity as it is kept in credits, which means no need to set quota. In addition, at the end of banking period, the left credits can be valued at zero. Utilities preferred to compensate the excess generation in real-time because it is allowed to set the buyback rate at the average wholesale price or lower. Whereas, the compensation of net metering scheme is allowed to set the buyback rate at full retail price, which may result in greater revenue losses to utilities. However, any scheme has an impact on utilities' revenue losses but the revenue losses might happen in different degrees. Whether government go forward for net metering, the question of the buyback rate may not be determined easily, which need to take into account like other factors.

In conclusion, the stakeholders' perspective above reflected their point of views on each element of self-consumption scheme, including net metering and net billing in order to design the potential scheme for promoting rooftop solar PV system in Thailand. Since natural energy transition from conventional energy sources to renewable energy sources may impact consequences for the utilities. So, they may need more ambitious in order to make a transition toward self-consumption scheme.

Question 4: What should be an appropriate self-consumption scheme?

Based on the overall results from economic feasibility analysis, sensitivity analysis, technical analysis and stakeholder's perspectives analysis, the appropriate self-consumption scheme for residential and commercial sectors is net metering with rolling credit and buyback scheme based on the most economic feasibility and most beneficial to the prosumers and private sectors in term of compensation for the excess net generation. The result of economic feasibility of this scheme shows lowest payback period and highest NPV among all the three schemes, which could return financial income faster. Providing this scheme to be implemented, the investment of rooftop PV system would become more attractive for residential and commercial sectors.

Besides, net billing with real-time buyback was feasible for residential TOU rate because they can produce the electricity during peak hour. Since, the electricity rate at peak time is higher and thus, electricity bill will be more saved. Further advantage, if there is excess generation during peak time, the prosumers will get higher compensation.

7.2 Policy recommendations and implications for research

The future policy of self-consumption schemes would implicate the policy change in Thailand renewable energy sector. The findings from stakeholders' perspective reflected that the prosumers and private sectors preferred excess generation of PV electricity can be kept as credit within banking period. Meanwhile, the utility authorities opted for compensation as real-time payment for the excess generation of electricity. The implication for scheme selection from stakeholders' perspectives could emerging insights on the future of policy and regulation electric power system point of view to greater attention to consumers' attitudes and behaviors and additionally calls for consumers' active participation in the decision making.

Based on Alternative Energy Development Plan (AEDP) policy, which is the plan for promoting renewable energy production for power generation within the full potential of domestic sectors. The increase target share of renewable energy consumption is expected to be upscale from the current 12% to 30% in 2036. The current updated solar roof power generation is 6,000 MW, which is double from two years ago.

By implementing the best scheme according to this research, it can assist to achieve this AEDP policy. To achieve the targeted policy, researcher recommended the few considerations that need to be taking into account:

- Towards policymaker perspectives:
    a. Based on the finding of focus group discussions and surveys, policymakers preferred compensation for excess generation of electricity for both storable credit and real-time payment. The implication for the current Thailand's self-consumption scheme is that the current policy should be change from no compensation to compensation for excess generation storable credit and real-time payment.
    b. Policy recommendation for policymakers for scheme selection is that all stakeholders should participate and give a collective decision making on the future of electric power system policy and regulation and maintain a stable policy framework for Thailand rooftop PV market.
- Towards Utilities perspectives:
    a. Based on the finding of focus group discussions and surveys, utilities preferred real-time payment as a compensation for excess generation of electricity. The reason being was that the real-time payment allows utilities to monitor the electricity load and the excess generation of electricity monthly and the buyback rate can be adjusted at flexible rate.

Comparatively to net metering, the utilities may lose their revenue because the buyback rate has to be valued at retail rate.

b. Another implication from utilities point of view was related to disruptive technology that solar PV excess generation should be allowed to be buyback, which equal and effective reflect the value of solar in terms of benefit of CO_2 emission reduction and the avoided of unities.

c. The future trends, the PV penetration will increase, hence, utilities need to adapt and accommodate all the policy changes, which relate to it. For example, utilities should seek alternative business model in order to cope with policy changes and able to forecast future solar PV increase in order to plan efficiency for investment.

d. Quantifying the soft costs and the non-technical barriers to PV adoption or quantifying the financial impacts of DPV on utilities. These topics are very important for designing a coherent support policy for rooftop PV and should be explored more in-depth in the future.

- Policy recommendation for people to act on:

  a. The findings from Chapter 4 demonstrated that rooftop solar PV system installation is now already economic feasibility for residential households and commercial sectors under all three supporting schemes.

  b. Since, the details of the policy scheme will have an impact on how consumers produce and use distributed solar PV systems in the future.

REFERENCES

Ackermann, T., Andersson, G., & Söder, L. (2001). Overview of government and market driven programs for the promotion of renewable power generation. *Renewable Energy, 22*(1), 197-204.

Agarwal, T. (2014). Explain about 3 Basic Types of Energy Meters?

Algaddafi, A., Altuwayjiri, S. A., Ahmed, O. A., & Daho, I. (2017). An Optimal Current Controller Design for a Grid Connected Inverter to Improve Power Quality and Test Commercial PV Inverters. *The Scientific World Journal, 2017*.

An, E.-A.-U. (2011). Smart Meters and Smart Meter Systems: A Metering Industry Perspective.

Arulkumar, K., Vijayakumar, D., & Palanisamy, K. (2016). Recent advances and control techniques in grid connected PV system–A review. *International Journal of Renewable Energy Research (IJRER), 6*(3), 1037-1049.

Bank of Thailand. (2017). Forecast Summary.

Bhattacherjee, A. (2012). Social science research: Principles, methods, and practices.

Blair, N., Dobos, A. P., Freeman, J., Neises, T., Wagner, M., Ferguson, T., . . . Janzou, S. (2014). *System advisor model, sam 2014.1. 14: General description*. Retrieved from

Branker, K., Pathak, M., & Pearce, J. M. (2011). A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews, 15*(9), 4470-4482.

Bruntland, G. (1987). Our Common Future-The Bruntland Report. *World Commission on Environment and Development*.

Chiaroni, D., Chiesa, V., Colasanti, L., Cucchiella, F., D'Adamo, I., & Frattini, F. (2014). Evaluating solar energy profitability: A focus on the role of self-consumption. *Energy Conversion and Management, 88*, 317-331.

Christoforidis, G. C., Panapakidis, I. P., Papadopoulos, T. A., Papagiannis, G. K., Koumparou, I., Hadjipanayi, M., & Georghiou, G. E. (2016). A model for the assessment of different Net-Metering policies. *Energies, 9*(4), 262.

Colmenar-Santos, A., Campíñez-Romero, S., Pérez-Molina, C., & Castro-Gil, M. (2012). Profitability analysis of grid-connected photovoltaic facilities for household electricity self-sufficiency. *Energy Policy, 51*, 749-764.

Colthorpe, A. (2017, Mar 02, 2017). Japan's big PV names targeting self-consumption and rooftop market. Retrieved from https://www.pv-tech.org/news/japans-big-pv-names-targeting-self-consumption-and-rooftop-market

Dahiya, B. (2016). ASEAN Economic Integration and Sustainable Urbanization. *Journal of Urban Culture Research, 13*(1), 8-15.

Daigle, P. (2000). Digital Energy Meters by the Millions. *Utility Automation, April*.

Darghouth, N., Barbose, G., & Wiser, R. (2013). *Electricity Bill savings from residential photovoltaic systems: Sensitivities to changes in future electricity market conditions*. Retrieved from

Darghouth, N. R., Barbose, G., & Wiser, R. H. (2014). Customer-economics of residential photovoltaic systems (Part 1): The impact of high renewable energy

penetrations on electricity bill savings with net metering. *Energy Policy, 67*, 290-300.
Daware, K. (2016). Energy Meters: Electromechanical and Electronic.
De Boeck, L., Van Asch, S., De Bruecker, P., & Audenaert, A. (2016). Comparison of support policies for residential photovoltaic systems in the major EU markets through investment profitability. *Renewable Energy, 87*, 42-53.
DEDE. (2016). Thailand Rooftop PV Pilot Project.
Dehler, J., Keles, D., Telsnig, T., Fichtner, W., & Baumann, M. (2015). Self-consumption of electricity from renewable sources. *INSIGHT_e, Karlsruhe Institute of Technology*.
Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and Sustainable Energy Reviews, 4*(2), 157-175.
DSIRE. (2017). Net metering.
Dufo-López, R., & Bernal-Agustín, J. L. (2015). A comparative assessment of net metering and net billing policies. Study cases for Spain. *Energy, 84*, 684-694.
Dusonchet, L., & Telaretti, E. (2010). Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries. *Energy Policy, 38*(7), 3297-3308.
Eid, C., Guillén, J. R., Marín, P. F., & Hakvoort, R. (2014). The economic effect of electricity net-metering with solar PV: Consequences for network cost recovery, cross subsidies and policy objectives. *Energy Policy, 75*, 244-254.
Eltawil, M. A., & Zhao, Z. (2010). Grid-connected photovoltaic power systems: Technical and potential problems—A review. *Renewable and Sustainable Energy Reviews, 14*(1), 112-129.
Firstenergycorp. (2016). Bi-directional Metering.
Fu, R., Chung, D., Lowder, T., Feldman, D., Ardani, K., & Margolis, R. (2016). US Solar Photovoltaic System Cost Benchmark: Q1 2016. *National Renewable Energy Laboratory, US Department of Energy. NREL/TP-6A20-66532*.
Germer, W. R., Ouellette, M. J., & Negahban-Hagh, M. (1991). Electronic meter digital phase compensation. In: Google Patents.
GIZ. (2017). *Thailand Solar PV Policy Update* Retrieved from http://www.thai-german-cooperation.info/admin/uploads/publication/384bf513d3c90d94c609e739be270b3den.pdf
Haas, R., Eichhammer, W., Huber, C., Langniss, O., Lorenzoni, A., Madlener, R., . . . Oniszk, A. (2004). How to promote renewable energy systems successfully and effectively. *Energy Policy, 32*(6), 833-839.
Holdermann, C., Kissel, J., & Beigel, J. (2014). Distributed photovoltaic generation in Brazil: An economic viability analysis of small-scale photovoltaic systems in the residential and commercial sectors. *Energy Policy, 67*, 612-617.
Huang, X., Wang, H., Wang, Y., & Xu, H. (2013). *Voltage rise regulation with voltage source inverter in grid connected PV generation system.* Paper presented at the Electrical Machines and Systems (ICEMS), 2013 International Conference on.
Hughes, L., & Bell, J. (2006). Compensating customer-generators: a taxonomy describing methods of compensating customer-generators for electricity supplied to the grid. *Energy Policy, 34*(13), 1532-1539.

IRENA. (2017). *REthinking Energy 2017: Accelerating the global energy transformation*. Retrieved from Abu Dhabi.:

Jacobson, M. Z., & Delucchi, M. A. (2009). A path to sustainable energy by 2030. *Scientific American, 301*(5), 58-65.

James, T. (2014). *Japan's Solar Photovoltaic (PV) Market: An Analysis of Residential System Prices (Presentation)*. Retrieved from

Joe Simon, G. M. (2013). *Feasibility Study of Economics and Performance of Solar Photovoltaics at the VAG Mine Site in Eden and Lowell, Vermont* Retrieved from

Jordan, D. C., & Kurtz, S. R. (2013). Photovoltaic degradation rates—an analytical review. *Progress in photovoltaics: Research and Applications, 21*(1), 12-29.

Karatayev, M., & Clarke, M. L. (2016). A review of current energy systems and green energy potential in Kazakhstan. *Renewable and Sustainable Energy Reviews, 55*, 491-504.

Kenning, T. (2017). Vietnam introduces utility-scale solar FiT and rooftop net metering. *PVTECH*. Retrieved from https://www.pv-tech.org/news/vietnam-introduces-utility-scale-solar-fit-and-rooftop-net-metering

Kittner, N., Gheewala, S. H., & Kamens, R. M. (2013). An environmental life cycle comparison of single-crystalline and amorphous-silicon thin-film photovoltaic systems in Thailand. *Energy for Sustainable Development, 17*(6), 605-614.

Klein, A., Held, A., Ragwitz, M., Resch, G., & Faber, T. (2008). Evaluation of different feed-in tariff design options: Best practice paper for the International Feed-in Cooperation. *Energy Economics Group & Fraunhofer Institute Systems and Innovation Research, Germany*.

Koumparou, I., Christoforidis, G. C., Efthymiou, V., Papagiannis, G. K., & Georghiou, G. E. (2017). Configuring residential PV net-metering policies–a focus on the Mediterranean region. *Renewable Energy*.

Krungsri. (2016). Power generation industry. *Thailand Industry Outlook 2016-2018*.

Luthander, R., Widén, J., Nilsson, D., & Palm, J. (2015). Photovoltaic self-consumption in buildings: A review. *Applied Energy, 142*, 80-94.

Masson, G., Briano, J., & Baez, M. (2016). Review and analysis of PV sef-consumtion policies. *International Energy Agency*.

MEA. (2016). Grid connection code.

MEA. (2017a). Electricity Tariffs.

MEA. (2017b). Grid-connected Inverter Approval List.

Mir-Artigues, P. (2013). The Spanish regulation of the photovoltaic demand-side generation. *Energy Policy, 63*, 664-673.

Mitsubishi Electric Automation. (2016). Watt-Hour Meter in The Digital Age. In M. E. A. (Thailand) (Ed.).

Nakada, S., Saygin, D., & Gielen, D. (2014). Global bioenergy supply and demand projections: a working paper for REmap 2030. *International Renewable Energy Agency (IRENA)*, 1-88.

Nikolaidis, A. I., & Charalambous, C. A. (2017). Hidden financial implications of the net energy metering practice in an isolated power system: Critical review and policy insights. *Renewable and Sustainable Energy Reviews, 77*, 706-717.

Nilsson, M., Lucas, P., & Yoshida, T. (2013). Towards an integrated framework for SDGs: Ultimate and enabling goals for the case of energy. *Sustainability, 5*(10), 4124-4151.

NREL. (2002). Connecting your Solar Electric System to the Utility Grid.

Pachanapan, P., & Kanprachar, S. Voltage Level Management of Low Voltage Radial Distribution Networks with High Penetration of Rooftop PV Systems.

Panwar, N., Kaushik, S., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: a review. *Renewable and Sustainable Energy Reviews, 15*(3), 1513-1524.

Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews, 15*(3), 1625-1636.

PEA. (2017). Grid-connected inverter Approval List.

Poblocka-Dirakis, A. (2017). Net Metering. from Renewable energy policy database and support http://www.res-legal.eu/search-by-country/denmark/

Poullikkas, A. (2013). A comparative assessment of net metering and feed in tariff schemes for residential PV systems. *Sustainable Energy Technologies and Assessments, 3*, 1-8.

Poullikkas, A., Kourtis, G., & Hadjipaschalis, I. (2013). A review of net metering mechanism for electricity renewable energy sources. *Int. J. Energy Environ, 4*(6), 975-1002.

Prakash, R., & Bhat, I. K. (2009). Energy, economics and environmental impacts of renewable energy systems. *Renewable and Sustainable Energy Reviews, 13*(9), 2716-2721.

Prol, J. L., & Steininger, K. W. (2017). Photovoltaic self-consumption regulation in Spain: Profitability analysis and alternative regulation schemes. *Energy Policy, 108*, 742-754.

Punyachai, R., Ongsakul, W., & Schmidt, U. (2014). *Impact of high solar rooftop pv penetration on voltage profiles in distribution systems.* Paper presented at the Green Energy for Sustainable Development (ICUE), 2014 International Conference and Utility Exhibition on.

PVPS, I. (2015). 2014 Snapshot of Global PV Markets. *Report IEA PVPS T1-26*.

Ramirez, A. D. (2006). Electricity meter with power supply load management. In: Google Patents.

Ramírez, F. J., Honrubia-Escribano, A., Gómez-Lázaro, E., & Pham, D. T. (2017). Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for European countries. *Energy Policy, 102*, 440-452.

Ren21, R. (2017). Renewable energyl status report. *Renewable Energy Policy Network for the 21st Century, Paris, France*.

Ridenour, R. E., & Swanson, S. (2001). Electricity meter. In: Google Patents.

Rodrigues, S., Faria, F., Cafôfo, N., Chen, X., & Morgado-dias, F. (2015). Small Scale Photovoltaic Analysis for the Residential and Commercial Market in Portugal. *International Journal of Chemical and Environmental Engineering (IJCEE), 6*(4).

Rodriguez-Calvo, A., Cossent, R., & Frías, P. (2017). Integration of PV and EVs in unbalanced residential LV networks and implications for the smart grid and advanced metering infrastructure deployment. *International Journal of Electrical Power & Energy Systems, 91*, 121-134.

Sharma, K., & Saini, L. M. (2015). Performance analysis of smart metering for smart grid: An overview. *Renewable and Sustainable Energy Reviews, 49*, 720-735.

Solar Power Europe. (2016). *Overview of The PV Investment Environment in Italy*. Retrieved from http://www.assorinnovabili.it/public/sitoaper/FontiRinnovabili/paper/2016/Investment%20Overview%20Italy%20November%202016.pdf

Sunshine, W. L. (2017, March 20, 2017). Pros and Cons of Smart Electric Meters. Retrieved from https://www.thebalance.com/pros-and-cons-of-smart-meters-1182648

Surachai Chaitusaney, Rongrit Chatthaworn, Pikkanate angaphiwatchawal, & Klansupar, C. (2017). Technical Impacts of increasing DPV: Voltage, Loss, and Peak load.

Teodorescu, R., Liserre, M., & Rodriguez, P. (2011). *Grid converters for photovoltaic and wind power systems* (Vol. 29): John Wiley & Sons.

Tongsopit, S. (2015). Thailand's feed-in tariff for residential rooftop solar PV systems: Progress so far. *Energy for Sustainable Development, 29*, 127-134.

Tongsopit, S., Chaitusaney, S., Julakarn, S., Wibulpholprasert, W., Kokchang, K., & Chaianon, A. (2017). *Report on Rooftop PV Pilot Project Evaluation*. Retrieved from

Tongsopit, S., Moungchareon, S., Aksornkij, A., & Potisat, T. (2016). Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. *Energy Policy, 95*, 447-457.

UN. (2016). Sustainale Development Goals.

Wan, Y.-H., & Green, H. J. (1998). *Current experience with net metering programs*. Retrieved from

Wan, Y. (1996). *Net metering programs*. Retrieved from

Wilkinson, P., Smith, K. R., Joffe, M., & Haines, A. (2007). A global perspective on energy: health effects and injustices. *The Lancet, 370*(9591), 965-978.

Yamamoto, Y. (2012). Pricing electricity from residential photovoltaic systems: A comparison of feed-in tariffs, net metering, and net purchase and sale. *Solar Energy, 86*(9), 2678-2685.

Zhang, F., Deng, H., Margolis, R., & Su, J. (2015). Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China. *Energy Policy, 81*, 43-55.

APPENDIX

Appendix A: Electricity tariff structure and load profile of residential and commercial consumers

Electricity tariff structure

i. *Base tariff*

Base tariff is reviewed every 3-5 years in order to reflect cost of power plants transmission and distribution system including fuel and O&M by considering the proper rate of utilities. The assumption included power consumption, fuel prices, and exchange rate and inflation rates.

ii. *Automatic Tariff Adjustment*

Ft is the variable tariff or tariff derived from the Automatic Tariff Adjustment Mechanism formula. It is reflected the change in uncontrolled cost of the utilities such as fuel cost and purchasing power in which are only differ from base tariff. Currently, it is important to encourage efficient procurement of generation from EGAT's own power plant and EGAT power purchasing from independents power produce (IPPs), small power producers (SPPs) and neighbor countries (Laos and Malaysia) as generation costs are the largest component of electricity costs. Ft also comprised the expense occurred form Government policies such as renewable policy (Adder, FiT) of SPP and VSPP and power development fund (MEA, 2017).

Basically, Ft is monitored by The Energy Regulatory Commission and revised every 4 month in line with changes in EGAT fuel cost, the power purchase cost, and the impact of policy expense, which are beyond control of the power utilities. There are 3 times per year, on January, May and September. For both MEA and PEA shows the Ft rate and Ft charge on electricity invoices every month.

iii. Vat

Besides base tariff and Ft, consumers have to pay valued added tax (VAT at 7%), which included base tariff and Ft.

Electricity consumer categories

MEA and PEA categories the component of electricity consumers into 8 classification, namely residential service, small general service, medium general service, large general service, specific business service, non-profit organizations, water pumping for agricultural purposes, and temporary tariff. The definition is following:

1. *Residential service*

This class is applicable to households and other dwelling places, monasteries, house of priests, and churched of any religious including its compound, through a single watt-meter. Electricity tariff of this class consist of two rate as following,

Normal rate

a. Consumption not more than 150 kWh per month

Energy charge		
First 15 kWh (1^{st}-15^{th})	2.3488	Baht/kWh
Next 10 kWh (16^{th}-25^{th})	2.9882	Baht/kWh
Next10 kWh (26th – 35th)	3.2405	Baht/kWh
Next 65 kWh (36th – 100th)	3.6237	Baht/kWh
Next 50 kWh (101st – 150th)	3.7171	Baht/kWh
Next 250 kWh (151st – 400th)	4.2218	Baht/kWh
Over 400 kWh (up from 401st)	4.4217	Baht/kWh
Service charge (Baht/Month) :	**8.19**	

b. Consumption more than 150 kWh per month

Energy charge		
First 150 kWh (1^{st}-150^{th})	3.2484	Baht/kWh
Next 250 kWh (151^{th}-400^{th})	4.2218	Baht/kWh
Over 400 kWh (up from 401st)	4.4217	Baht/kWh
Service charge (Bah/Month)	38.22	

c. Time of use tariff (TOU tariff).

	Energy charge (Baht/ kWh)		Service charge (Baht/month)
	On Peak	Off Peak	
12-24 kV	5.1135	2.6037	312.24
Below 12 kV	5.7982	2.6369	38.22

On Peak: Monday – Friday from 09:00 am to 10:00 PM

Off Peak: Monday – Friday from 10:00 PM to 09:00 AM

Saturday – Sunday, National Labor Day and normal public holiday

(Excluding substitution holiday and Royal Ploughing Day) from 00:00 AM to 12:00 PM

(2) Small General service

This class is applicable to a business enterprise, business enterprise cum residence, industrial, government institutions and state enterprise or the alike, including its compound, with a maximum 15-minute integrated demand of less than 30 kilowatt through a single Watt hour meter. Electricity tariff for this class divides into two tariffs

a. Normal tariff

Voltage level	Energy charge (Baht/kWh)	Service charge (Baht/month)
12-24 kV	3.9086	312.24
Below 12 kV		46.16
First 150 kWh (1^{st}-150^{th})	3.2484	
Next 250 kWh (151^{th}-400^{th})	4.2218	
Over 400 kWh (up from 401st)	4.417	

b. Time of use tariff (TOU tariff)

	Energy charge (Baht/ kWh)		Service charge (Baht/month)
	On Peak	Off Peak	
12-24 kV	5.1135	2.6037	312.24
Below 12 kV	5.7982	2.6369	46.16

On Peak: Monday – Friday from 09:00 am to 10:00 PM

Off Peak: Monday – Friday from 10:00 PM to 09:00 AM

Saturday – Sunday, National Labor Day and normal public holiday

(Excluding substitution holiday and Royal Ploughing Day) from 00:00 AM to 12:00 PM

(3) Medium general service

This class of tariff is applicable to business, industrial, government institutions and state enterprises, as well as the foreigner entities and international organizations including its compound, with a maximum 15-minute integrated demand from 30-999 kilowatts.

Of which the average energy consumption for three (3) consecutive months through a single watt-hour meter does not exceed 250,000 kWh per month

a. Normal tariff

Voltage level	Demand charge (Baht/ kW)	Energy charge (Baht/kWh)	Service charge (Baht/month)
69 kV and over	175.70	3.1355	312.24
12-24 kV	196.26	3.1729	312.24
Below 12 kV	221.50	3.2009	312.24

b. TOU rate

Voltage level	Demand charge (Baht/ kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
69 kV and over	74.14	0	4.1283	2.6107	312.24
12-24 kV	132.93	0	4.2097	2.6295	312.24
Below 12 kV	210.00	0	4.3555	2.6627	312.24

(4) Large general service

This class of tariff is applicable to a business, industrial, government institution, state enterprise, foreign entities and international organizations, including its compound, with a maximum 15-minnute integrated demand over 1,000 kilowatt, or the energy consumption for three (3) average consecutive months through a single Watt-hour meter exceeds 250,000 kWh per month.

a. Time of day tariff (TOD tariff)

Voltage level	Demand charge (Baht/ kW)			Energy charge (Baht/kWh)	Service charge (Baht/month)
	On Peak	Partial Peak	Off peak	All times	
69 kV and over	224.30	29.91	0	3.1355	312.24
12-24 kV	285.05	58.88	0	3.1729	312.24
Below 12 kV	332.71	68.22	0	3.2009	312.24

b. Time of use tariff (TOU tariff)

Voltage level	Demand charge (Baht/ kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
69 kV and over	74.14	0	4.1283	2.6107	312.24
12-24 kV	132.93	0	4.2097	2.6295	312.24
Below 12 kV	210.00	0	4.3555	2.6627	312.24

(5) Specific business service

This class of tariff is applicable to any hotel and other business providing lodging accommodation to their customers including its compound with a maximum 15-minute integrated demand of 30 kilowatt and over, through a single Watt hour demand meter

a. Normal tariff

Voltage level	Demand charge (Baht/ kW)	Energy charge (Baht/kWh)	Service charge (Baht/month)
69 kV and over	220.56	3.1355	312.24
12-24 kV	256.07	3.1729	312.24
Below 12 kV	276.64	3.2009	312.24

b. Time of use tariff (TOU tariff)

Voltage level	Demand charge (Baht/ kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
69 kV and over	74.14	0	4.1283	2.6107	312.24
12-24 kV	132.93	0	4.2097	2.6295	312.24
Below 12 kV	210.00	0	4.3555	2.6627	312.24

(6) Non-profit organizations

This class of tariff is applicable to non-governmental organizations that provide non-charge services including places conducting religious rites and their compounds though a single Watt-hour meter, not application to the state enterprises, embassies, foreign entities and office buildings of international organizations.

a. Normal tariff

Voltage level	Energy charge (Baht/kWh)	Service charge (Baht/month)
69 kV and over	3.4407	312.24
12-24 kV	3.6107	312.24
Below 12 kV		20.00
First 10 kWh (1st-10th)	2.8271	
Over 10 kWh (Up from 11st)	3.9177	

b. TOU tariff

Voltage level	Demand charge (Baht/ kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
69 kV and over	74.14	0	4.1283	2.6107	312.24
12-24 kV	132.93	0	4.2097	2.6295	312.24
Below 12 kV	210.00	0	4.3555	2.6627	312.24

(7) Water pumping for agricultural purposes

This class of tariff is applicable to electricity consumption for the use of water pumps for agricultural purpose of government agricultural agency, officially-recognized farmer groups, and agricultural co-operatives through a single Watt-hour meter.

a. Normal tariff

Energy charge	Energy charge (Baht/kWh)
First 100 kWh (1st-100th)	2.0889
Over 100 kWh (Up from 101st)	3.2405
Service Charge (Baht/month)	115.16

b. TOU rate

Voltage level	Demand charge (Baht/ kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	On Peak	Off Peak	On Peak	Off Peak	
12-24 kV	132.93	0	4.1839	2.6037	228.17
Below 12 kV	210.00	0	4.3297	2.6369	228.17

(8) Temporary tariff

This class of tariff is applicable to temporary electricity consumption for the use of the construction of buildings or structures, the special time event or the temporarily work, through a single Watt-hour meter

Monthly tariff	Baht per kWh
Energy charge (All voltage level)	6.8283

Appendix B: Survey Questionnaire of design supporting scheme for rooftop solar PV system in Thailand

แบบสอบถาม

การวิเคราะห์มุมมองต่าง ๆ ของผู้มีส่วนได้ส่วนเสียในนโยบาย และการออกแบบรูปแบบนโยบาย การส่งเสริมระบบผลิตไฟฟ้าจากพลังงานแสงอาทิตย์บนหลังคา (Rooftop PV) ในอนาคต

คำชี้แจง แบบสอบถามนี้เป็นส่วนหนึ่งการวิเคราะห์ผลดำเนินงานโครงการนำร่อง (Pilot project) การผลิตไฟฟ้าพลังงานแสงอาทิตย์ บนหลังคาอย่างเสรี โดยคณะผู้วิจัยฯ ได้รับการมอบหมายจากคณะทำงานกำหนดแนวทางดำเนินการและประสานงาน กำกับติดตามโครงการนำร่องฯ (Pilot project) กระทรวงพลังงาน ในการดำเนินการศึกษาครั้งนี้

แบบสอบถามนี้จัดทำขึ้น โดยมีวัตถุประสงค์ให้แสดงความคิดเห็นในผลกระทบที่จะเกิดขึ้นจากนโยบายการส่งเสริมระบบผลิตไฟฟ้าจากพลังงานแสงอาทิตย์บนหลังคาต่อผู้มีส่วนได้ส่วนเสียในมุมมองต่างๆ และเพื่อนำมาวิเคราะห์ในการออกแบบรูปแบบนโยบายส่งเสริมการผลิตไฟฟ้าจากระบบพลังงานแสงอาทิตย์บนหลังคาที่**เหมาะสมในอนาคต**

ส่วนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

โปรดทำเครื่องหมาย ✓ ลงในช่อง ☐ (กรุณาตอบแบบสอบถามทุกข้อเพื่อให้ได้ข้อมูลที่สมบูรณ์)

1. ชื่อ-นามสกุล...
2. ตำแหน่ง..
3. หน่วยงาน (ส่วน/โครงการ/ฝ่าย)..
4. สังกัด..
5. เพศ ☐ ชาย ☐ หญิง
6. อายุ ☐ 20-30 ปี ☐ 31-40 ปี ☐ 41-50 ปี ☐ มากว่า 51 ปี
7. อีเมล์...
8. เบอร์โทรศัพท์..
9. บทบาทของผู้มีส่วนได้ส่วนเสีย โปรดเลือก:

   ☐ ผู้บริโภค ☐ ผู้ประกอบการ ☐ ผู้ออกแบบนโยบาย ☐ การไฟฟ้าฯ

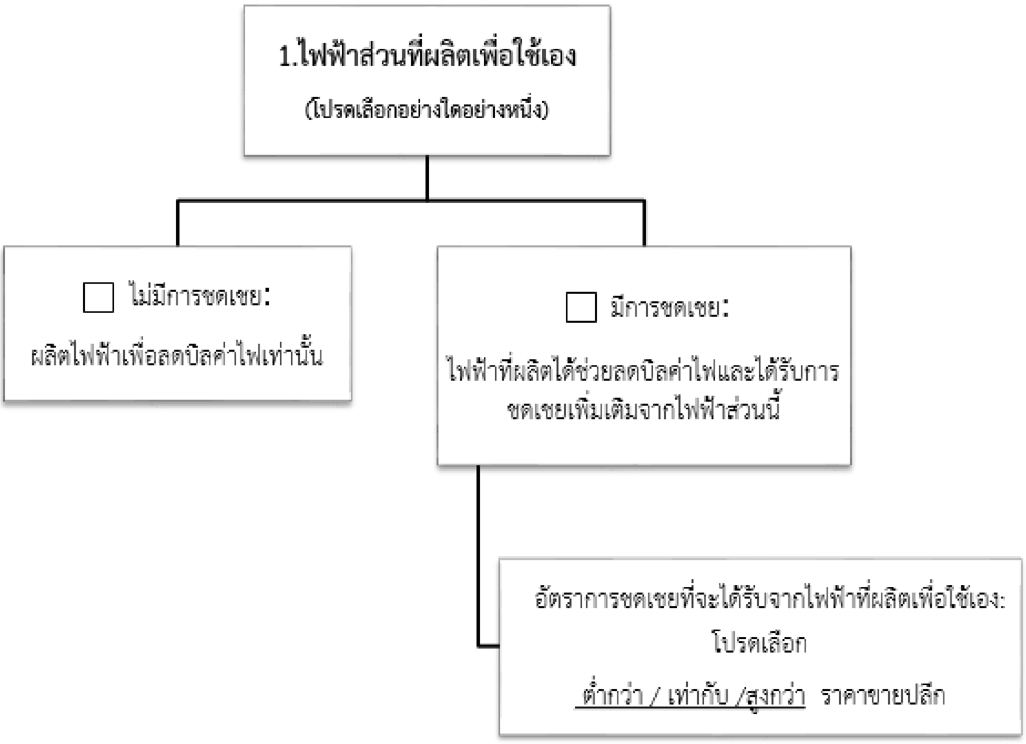
   ☐ อื่นๆ โปรดระบุ..

<u>ส่วนที่ 2</u> รูปแบบนโยบายส่งเสริมการผลิตไฟฟ้าจากระบบพลังงานแสงอาทิตย์บนหลังคาที่ท่านอยากให้เกิดขึ้น

<u>คำชี้แจง</u>: กรุณากรอกข้อมูลให้ครบถ้วน**<u>ทั้งสองข้อ</u>** คือ **ข้อ1. ไฟฟ้าที่ผลิตเพื่อใช้เอง และข้อ 2. ไฟฟ้าที่ผลิตได้ส่วนเกิน สำหรับรูปแบบนโยบายที่<u>ท่านอยากให้เกิดขึ้นในอนาคต</u>**

โปรดทำเครื่องหมาย ✓ ลงในช่อง ☐ และ ◯ วงกลมตัวเลือกสำหรับคำตอบของท่าน ในช่องโปรดเลือก

1.



ข้อเสนอแนะอื่นๆ...

....

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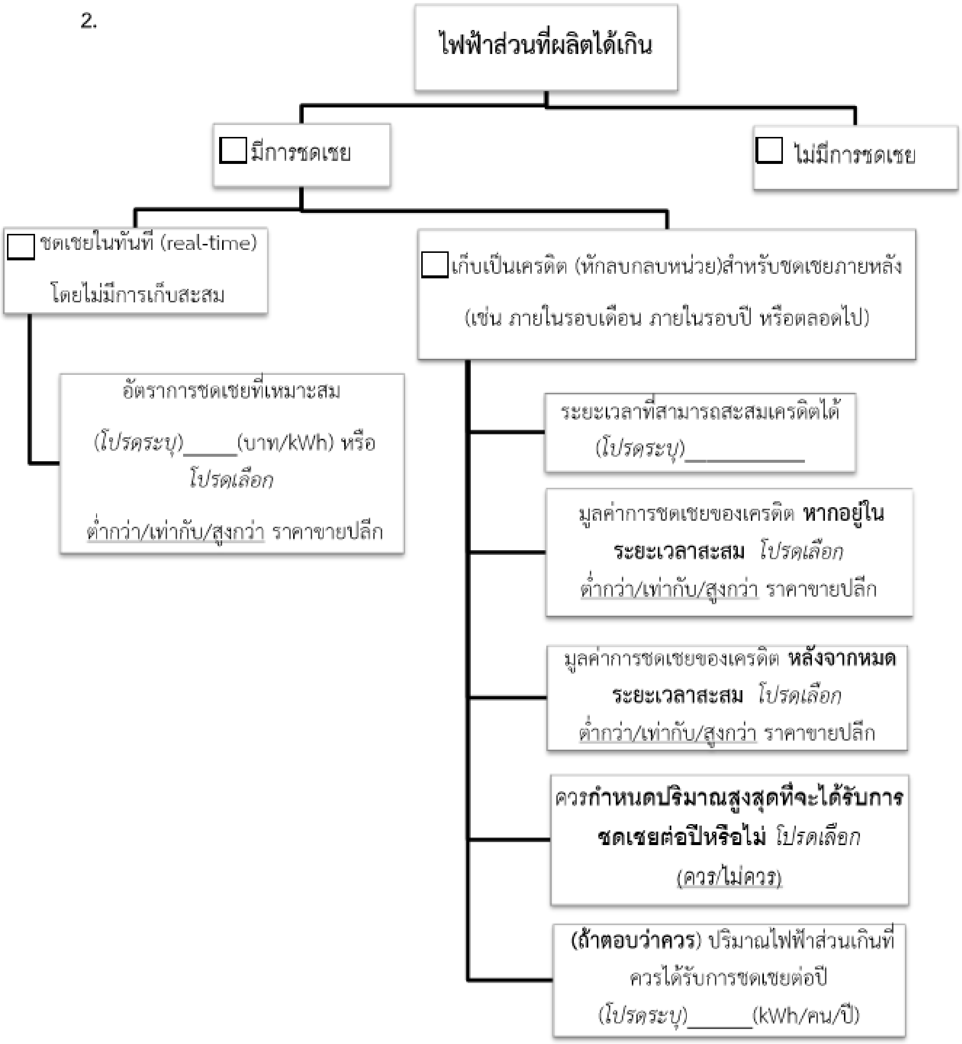
2.



ข้อเสนอแนะอื่นๆ...

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VITA

Miss Kespanerai Kokchang was born in Bangkok, Thailand, on 11 May 1989. Sheinished her Bachelor degree in Engineering Management from Sirindhorn International Institute of Technology, Thammasat University in 2011. She continued studying Master Degree in Heriot-watt University, Edinburgh, Scotland and completed the Master degree in Energy in 2013.

After Master degree completion, She flew back to Thailand and continued studying Doctoral program and applied in Environment, Development, and Sustainability program, Chulalongkorn University in 2014, by focusing on renewable energy particularly solar energy rooftop. During the Doctoral journey, she had opportunity to become research assistant of her advisor, Dr. Sopitsuda Tongsopit in the Rooftop Pilot Evaluation Project under the Energy Conservation Promotion Fund (ENCON fund).