The Transition from Conventional Energy to the Photovoltaic Systems and its Struggle under the Dominant Electricity Regime in Thailand

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Abstract

Electricity in Thailand has been heavily dependent on fossil-based fuels, and centrally controlled by the government and associated technocrats. Global issues, such as Cold War, oil and financial crises, along with environmental concerns, have considerably affected the dominant electricity regime of Thailand and driven it towards seeking renewable sources of energy for electricity generation. Photovoltaics, despite its high potential as a sustainable source of electricity, however, remains a supplementary production in the existing electricity regime, not the future electricity transition. In this study, archival data, interviews, and case studies had been analyzed and it was found that the photovoltaic systems in Thailand accounted for only 2.6% of the nation's total capacity in 2014 while the number is expected to rise to only 8.5% in 2036. Using the Multi-Level Perspective (MLP) concept from the system innovation transition theory, this study explained why photovoltaics cannot be developed into a dominant source of electricity in Thailand. This study also discovered that the development of photovoltaics at the niche level the electricity regime's existing governance, technology, centralized production and distribution, supply and demand chains of commercial appliances, and culture of the electricity users are not supportive of the photovoltaic systems. Therefore, without significant technological breakthrough and sincere commitment to energy reforms, the photovoltaic systems will continue to struggle and cannot become a major element of the future electricity transition in Thailand.

Keywords: Multi-Level Perspective, Landscape change, Thai electricity regime, Photovoltaics

Introduction

Thailand's economy relies heavily on electricity generated from fossil energy. Thai electricity has been developed and controlled by politicians, bureaucrats, and technocrats through such state enterprises as Electricity Generating Authority of Thailand (EGAT), Metropolitan Electricity Authority (MEA), and Provincial Electricity Authority (PEA) which are dominant and influential stakeholders of the regime. Affected by Cold War, oil and financial crises, along with increasing concerns about global warming, Thai electricity regime has been driven to seek renewable sources of energy for electricity generation and adapt their policies accordingly.

There are pieces of evidence that most developed countries have succeeded in raising a greater contribution to electricity generation from renewable energy (IEA, 2015), while Thai electricity regime has maintained its dominant role in generating and distributing power through fossil energy, providing stability and reliability as its justification. However, to reduce the pressure from global warming concerns, photovoltaics (PV) has been adopted as an adaptive strategy. Until recently, PV had been developed through a centrally controlled apparatus, not small-scaled and independent enterprises, and the electricity generated from PV was distributed and sold solely by the regime for a period of over 39 years (from 1976 to 2015). According to German International Corporation (GIZ)'s report, the

contribution from PV to the total electricity in Thailand in 2015 was only 2.6% (GIZ, 2015). This situation represents a big challenge to the transition in the production, distribution, and utilization of electricity in Thailand.

The Multi-Level Perspective (MLP) from the System Innovation Transitions theory (Geels, 2002, 2005a) was applied as a conceptual framework for this paper. The objectives of this paper were: (a) to review retrospectively the development of Thai electricity regime which relied heavily on fossil fuel and (b) to analyze the consequences of the social-technical and economic configuration of the PV systems through the interaction and influences of the Thai electricity regime under landscape changes, regime adaptation and novelty/niche experiments using the Multi-Level Perspective framework.

Multi-Level Perspective as a Framework for Analysis of the Dominant Thai Electricity Regime

PV has a high potential as an alternative source for electricity generation in Thailand, but its power contribution to co-exist with the fossil-based sources remains skeptical. This research adopted the theory of Multi-Level Perspective (MLP) as a conceptual framework with the focus on the transition of long-term analysis (Verbong & Geels, 2007) to analyze the transition of the electricity regime. The transition of a large scale of innovation can be defined as major, long-term processes of socio-technological changes in relation to basic human needs (Elzen & Wieczorek, 2005). Innovation emerges when the existing systems fail to fit the needs of the society. In the socio-technical process, the potential innovations are developed and accepted as mainstream. The appropriate framework for understanding this innovation transition process is Geels's theory of Multi-Level Perspective, which displays and distinguishes three heuristic levels of technological transitions as follows; 1) technological niche, 2) socio-technical regime, and 3) socio-technical landscape or landscape development as a nested hierarchy to understand innovation transitions (Geels, 2005a).

The first level or the technological niche (micro level) is assumed to be the beginning of a major transition and provides locations for learning processes and space to build a social network (Geels, 2005b). Niche actors hope that the promising novelties are eventually used in the regime or even replace it (Geels, 2004). The technological niche and socio-technical regime are similar kinds of structuration of activities comprising of politics, policy and implication, science and technology, industry, market, and socio-culture; both niche and regime have a character of the organizational field.

The second level or the socio-technical regime (meso level) is a coherent, high-interrelated and stable structure (Jochen & Bernhard, 2008) which has been used to consider the stability of an existing socio-technical system or dominant culture structure and practices (Nykvist & Whitmarsh, 2008) such as stable configurations of institutions, techniques and artifacts, rules, practices, and networks (Rip & Kemp, 1998). The socio-technical regime or the emerging innovation is not independent of internal and external forces which consist of slow change events, gradients for the trajectories, and wider societal and cultural characteristics and trends (Elzen & Wieczorek, 2005; Geels, 2002). Wars, economic crises, and environmental crises emerging at the global scale would eventually put pressure on technical and socio-technical regimes as well as increase awareness from the civil society. For this reason, the socio-technical regime would be under a situation of turbulence for adaptation from both external landscape changes and internal pressure (Geels, 2002; Geels & Schot, 2007).

The third level or the socio-technical landscape or landscape development (macro level) represents the external environment of process and factors that influence both regimes and niches (Jochen & Bernhard, 2008) which provide even stronger structuration of activities than regimes (Geels, 2004). The socio-technical landscape contains a set of heterogeneous factors, which consist of slow change events, providing gradients for the trajectories and comprising wider societal and cultural characteristics and trends such as wars, oil crisis, financial crisis, global warming and environmental awareness (Elzen & Wieczorek, 2005; Geels, 2002). The context of landscapes is even harder to change than that of regimes. However, in a specific situation, landscapes can be changed but more slowly than regimes (Geels, 2002) (Figure 1).

The theory of MLP has been applied to the studies on transitions and system changes in developed nations Applying MLP for a framework for studying energy transitions in developed countries such as Thailand is challenging. The Thai electricity regime has been inevitably affected by external pressures. It has to adapt either to maintain a status quo or to open windows of opportunity for new innovations. The PV systems could be an adaptation of the regime or innovation if properly developed, and it would become a pathway towards replacing the existing regime. However, the process is not straightforward because it has to interact with complex factors (Geels, 2005a; Rip & Kemp, 1998). They include the typology of transition pathways based on the timings and nature of multi-level interactions (Geels & Schot, 2007), and different timing induces different responses at each level.

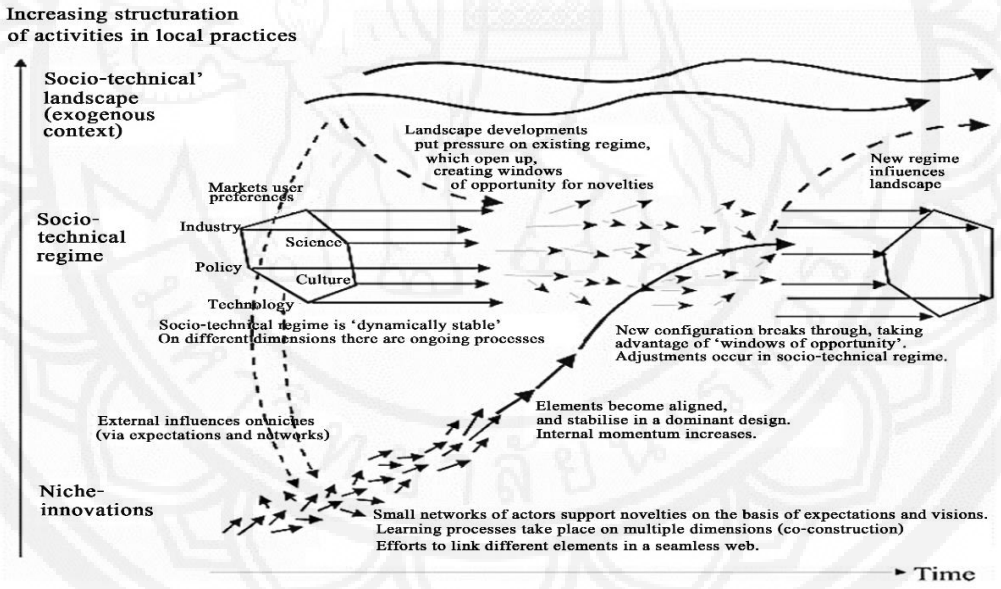

Figure 1 Multi-level Perspective on transitions (Geels, 2002; p. 1263)

Based on the MLP's description, the Thai PV systems can emerge, be developed at the niche level, and be upscaled to become a trajectory pathway, which can then change or replace the existing regime and transition into the new regime in the long run. If the process is independent of obstacles from multi-dimensions, especially the resistance from the socio-technical regime, then the PV development may face with two problems: a) the basic elements and resources of the PV systems and networks do not link together, and b) the existing regime has obstructed the PV systems on niche experiments. Therefore, if we need to upscale the PV systems, the governance of the regime should be reconfigured and the niche process should be applied under the Strategic Niche Management perspective

to contribute to sustainable development (Rip & Kemp, 1998). In the case of Thailand, the PV development is different from the literature as technological niches are defined as the establishment of a new socio-technical regime (Geels & Schot, 2007). So, the PV cumulative capacity is dependent on the government targets and the renewable energy plans which differ from time to time.

Methodology

To deal with challenges and achieve the objective, the mixed methods were used to collect empirical qualitative and quantitative data based on the MLP framework. Analysis of these data was completed retrospectively with regards to becoming the dominant regime and its impacts on the PV systems during major landscape changes. Collecting documents and statistics concerning the development and capacity of electricity regime and PV systems was done as secondary sources of data while interviewing key actors of both systems and reviewing case studies of PV off-grid systems as primary sources of data. At each period, holistic determinant factors or the structuration of activities are synthesized for a conclusion of characteristics of both the regime and PV.

Results

According to the MLP framework operationalized by the structuration of activities, important holistic and interrelated factors contribute to the development and potential transition of the system including politics and policy, science and technology, market, industry, and user preference/socio-culture. The results of this study were based on the analyses of any socio-technical system such as Thai electricity to be developed and become a mainstream instrument for the society through undergoing the structuration of activities. When a societal demand is evident from landscape changes as the external factors and internal pressure as a social movement, a strong and responsive political system will be one of the factors influencing the development of the system. In addition, with effective novelty form advanced science and technology, supportive market, expansion of business and industry, together with socio-culture of the emerging system, the system will be developed and become the mainstream in the future. The substantive analyses of (1) the dominant regime of Thai electricity and the political system and (2) the photovoltaic system and its relationship with the Thai electricity regime as a result will be presented respectively.

1. The dominant regime of Thai electricity and the political system

1.1 Development of Thai electricity regime before 1970 and external influences from Cold War and US assistance

Thailand's electricity system was firstly imported from Europe in 1884. Between 1932 and 1947, the political system under "military dictatorships" at that time, which began some decades ago, flourished through US assistance to the country to counterbalance the communist power in the area, resulting in massive construction developments of infrastructures. Acceleration of electrical supplies to meet development demands was eventually evident from the rapid construction of plants, transmission lines, and operating public enterprises (Padmanabhan, 1983). Electrical appliances started to be supplied by foreign businesses to meet the needs of the urban economy

and people. At this period, electricity was perceived as one of the main factors supporting industrialization as well for people living in the urban area.

As a result of these combined factors, Thai electricity generation from the 1930s until 1970 was characterized as the beginning of the socio-technical regime which was controlled and monopolized by the government through its state enterprises such as PEA, MEA, and other electrical authorities in each region. In 1969, when the government merged three electrical units to establish Electricity Generating Authority of Thailand (EGAT) which became the major power producer controlling the electricity transmission business. However, no regime could avoid escaping challenges that affect its stability. Landscape changes as well as internal shifts of political power eventually brought about a system adjustment of the regime to regain its stability.

1.2 Adaptation to the landscape change of oil price crisis (1970 - 1990)

In the early 1970s, the power generation of nearly three-quarters of commercial energy relied on imported oil (Kirtikara, 2004). Later, owing to landscape changes from the oil price crisis, the electricity production, for the first time, faced with the problem of seeking sustainable sources of energy. The discovery of natural gas in the Gulf of Thailand solved the problem and made the regime more stable from the natural gas supplied by Petroleum Authority of Thailand (PTT), another public enterprise which later on became a public company resulting from the privatization policy.

Moreover, the agreement following Plaza Accord (1985) resulted in more foreign investments in Thailand and developments were directed toward industrialization. Eastern Seaboard project was constructed to support export-oriented and petrochemical industries. This phenomenon enhanced the business of EGAT, PEA, and MEA and the Thai electricity regime.

During this period, politics and policies appeared to be supportive of the ongoing regime. The political system was referred to as "semi-democracy" under the semi-conservative leadership of General Prem Tinsulanondain. It was the system in which politicians who came into power through elections took more share of power from the military and bureaucrats. There were more utilizations of natural gas as well as allowing businesses related to politicians to invest in a fossil-based power generation (Langculanon, 2009). As a result, the regime expanded its operation and distribution substantively under a stronger control by the government.

Due to economic growth and more convenient access to electricity, the socio-culture of all urban people and some rural people changed in terms of living lifestyle. By the end of the 1970s, 36% of Thai people gained accessed to electricity from the previous ratio of 10% (HPEA, 2015), while the number increased to 99.3% in 2013 (Quang Cu Tran, 2013).

Despite the first turbulence from the landscape change of oil price crisis, the Thai electricity regime at this period was characterized by the great expansion of fossil-based energy with the largest distribution coverage due to the fortunate gas discovery and supportive structuration of activities. The regime's stability was maintained and the generating capacity increased from 1,169 MW in 1971 to 3,483 MW in 1976 (NESDP, 1977).

1.3 The 1997 Asian monetary crisis, global warming, environmental awareness and PV as the regime's adaptation (1990 - present)

This period saw two major landscape changes and political turbulence that affected the regime's stability and its adaptation to control the PV development. The Asian financial crisis started in Thailand with the financial collapse of the Thai Baht that occurred in 1997 and pushed the Thai economy to a critical situation. This period also observed rising concerns on global warming and attempts to reduce pollutants among the middle-class society (Forsyth, 2007). Along with external pressure, there was a radical shift in the political system from semi-democracy to more democracy. This shift resulted in a "politico-business" system in which the electricity regime was dominated by businesses involving politicians (Pasuk & Baker, 2004). As conflicts of interest grew, the military staged a coup d'etat with support of the urban middle class in hopes of radically reforming the nation (Langculanon, 2009). This incident resulted in the biggest shift at the socio-political level that considerably shaped the nature of the Thai electricity regime.

The Thai government received a financial recovery aid from International Monetary Fund (IMF) in July 1997 as a solution to the monetary crisis. Consequently, the policy calling for privatization of public enterprises by the politico-business government was implemented in accordance with the 'Letter of Intent' (LOI) to the IMF (Sirasoontorn, 2004). EGAT and PTT were successfully privatized as public companies in 2001 and 2005 respectively. But owing to the non-transparent procedures, the Supreme Administrative Court ordered EGAT in 2006 to remain a state enterprise. (A Judgment of the Supreme Administrative Court, 5/2548).

Before the Supreme Administrative Court's order, the privatization of EGAT led to changes resulting in Independent Power Producer: IPP, Small Power Producer: SPP and Very Small Power Producer: VSPP programs. EGAT decentralize the power production (in 1992, 1994 and 2002) and opened opportunities for private businesses to invest in power generation with EGAT as the single buyer. The roles of EGAT began to grow from a single producer to an enhanced single buyer and major shareholder of independent power producers. All of these incidents increased benefit sharing among energy business conglomerates. While EGAT continued to monopolize the supply of electricity, PTT became the sole supplier of natural gas to EGAT. As a result, these two public agencies have enjoyed benefits and control over Thai energy.

In response to the internal pressure from urban environmental advocacy groups and the educated middle class, the politico-business government and the regime made some changes to initiate and develop alternative energy including PV, but as populism policy. In particular, several promoting renewable policies were in place as Renewable Portfolio Standard: (RPS 2005), the 15-Year Renewable Energy Development Plan (REDP: 2008-2022) and Alternative Energy Development Plan (AEDP; 2012-2021). These situations opened an opportunity for the emergence of private power producers using renewable energy via the PV grid-connected system under SPP and VSPP programs. In 2016, the approximate system-generating capacity proportion of EGAT, IPP, and SPP, was 41%, 37%, and 13% respectively (MoEn, 2016).

1.4 Development on science and technology

In the beginning, the power plant technology was started using steam turbines and many provincial power plants used small diesel generators. Changes occurred only when there was a shift from the oil and lignite power generating system to a natural gas one. The natural gas power generation system has continued to be the main component of power generation until the present day. Alternatively, the government has considered a nuclear power

plant, however, the nuclear power generation is still in Power Development Plan (PDP). Meanwhile, as the regime was affected by the oil crisis in the 1970s, Thailand has since then been on the path of exploring and developing renewable energy. Solar, wind, and geothermal energy have been under consideration. Since the early 1980's, alternative energy has been included in the national economic and social development plans and photovoltaics were first incorporated into the 5th national plan (1982-1986) (Kirtikara, 2004).

However, the development on science and technology of the electricity system in Thailand is ineffective due to the lack of a) electrification of large sectors of the economy e.g. transportation and heating b) decentralization of power production plants e.g. lower distributing cost and more flexibility for demand and energy efficiency and c) digitalization e.g. smart metering, smart sensors, automation, and other digital network technologies.

1.5 Industry and market

Since the government started a policy for import substitution in 1960, the industry of producing electrical appliances has grown rapidly. Japanese companies have established businesses and invested their manufacturing plants in Thailand. Presently, electrical appliances are household equipment and the competition is on power-saving efficiency and product quality. Electrical appliances are a main part of the livelihood and people are highly dependent on electricity. This incidence indicates the need for the electricity regime to be strong and reliable. However, there are no significant industries for power generating equipment and machines, except for cables and wires.

1.6 Socio-culture of the Thai society

In the beginning, electricity served as means to achieve a comfortable life but it later became part of the basic necessities for Thai households. Even in rural areas, there is an electricity demand. This period has seen the transformation of generating power from conventional sources to that from alternative energy sources. At the same time, an anti-fossil-based power generation movement has been started by NGOs and environmental pro-activists with such examples as the cases of Mae Moh lignite-fired power plant, Pak Mul dam, and Rasi Salai dam (Amornsakchai et al., 2000; Dulin, Franko, Heun, & Masterson, 2008; Eley, Grant, Kulinlina, & Sanseverino, 2008), Bonok and Hin Krud projects, and Krabi coal-fired power plant (Greenpeace, 2014). In the 1990s, such social movement has started to become a driving force in society to call for political stances on cleaner energy (Forsyth, 2007).

1.7 Characteristics of the dominant Thai electricity regime

The main characteristics of the Thai electricity regime are a result of landscape changes by a series of environmental conservation movements and transparency in government policies. Likewise, environmental activist groups have been internally pressurizing the regime against the use of fossil-based energy. The regime has been pressured to undergo a major adaptation to maintain its dominance. The regime's policies and implementations have been two folds. Firstly, PPT was privatized and fossil-based power generation plants were supported under the control of the regime. Secondly, the regime began to develop the PV systems but with minimal impacts in response to the pressure. All in all, the regime can remain its dominant nature of fossil-based electricity while PV was initiated, though centrally, not at the niche level. At present, the regime manages power for the total capacity of 42,209.25 MW in 2018 (EGAT, 2018), of which the proportion from fossil base is 78.1 % (mostly from natural gas or 60.2%) while that from non-fossil base (hydroelectricity) is 2.3%, that of imported electricity is 12.1%,

and that from renewable energy is 7.4% (EPPO, 2017). Finally, the emergence and development of the regime can be clearly seen through the structuration of activities in Table 1.

2. The photovoltaic system and its relationship with the Thai electricity regime

2.1 Emergence and development of the photovoltaic system as the regime's adaptation

By and large, PV in Thailand was started independently and at a very small scale in 1976 and has since been developed substantively by the influence of such landscape changes as oil crisis as well as global warming and environmental awareness (1990 – present). PV was firstly used in Thailand in 1976 by the Princess Mother's Medical Volunteer Foundation (PMMV) to support mobile telecommunication units that conducted field work in remote rural areas. At the time, NASA's Lewis Research Center started a larger scale of PV implementation in a rural area in many parts of the continents.

In the 1970s, the oil crisis resulted in a new energy policy to reduce energy import and to diversify energy sources. The government under the semi-democratic political regime became involved in the development of non-conventional and renewable sources of energy. In the 5th National Plan (1982-1986), the National Research Council of Thailand established a sub-committee on energy research and commissioned a working group for PV development. The PV off-grid system was later introduced mostly in rural areas. It was carried out by such agencies as Department of Primary Education under Ministry of Education, Department of Public Work (DPW) under Ministry of Interior, and Department of Energy Development and Promotion (DEDP) under Ministry Science Technology and Environment. By 1996, the PV off-grid system was cumulatively installed about 2.5 MWp (Kirtikara, 1997, 2004). Initially, the capacity of PV gradually increased mostly by agencies in areas inaccessible of electricity. Therefore, in the early state, Thai PV was developed outside the Thai electricity regime. It emerged as a niche in line with explanations from the MLP framework.

With regards to the political aspect, the PV development in remote areas was initiated in needs of political supports from people at grassroots. They promoted the Solar Home System (SHS) project implemented by PEA during 2004-2005 as a populist campaign, resulting in a leap of the cumulative PV off-grid system's installation in 2006 about 24.6 MWp. (Figure 2).

With the ratification of United Nations Framework Convention on Climate Change (UNFCC) and the Kyoto Protocol to reduce external pressure as global warming and environmental awareness, the government has set several long-term energy plans. These plans have set a challenging target of increasing renewable energy shares in the final energy consumption mix, especially from PV. In 2007, the government initiated a solar farm and solar rooftop under SPP and VSPP programs with financial incentives called ADDER. Later, in 2013, a subsidy called feed-in tariff was enacted to replace ADDER for cost reduction. As a result of renewable energy policies implemented by AEDP, the power generation from the solar system was targeted at 3,000 MW in 2017 and at 6,000 MW in 2013, respectively (GIZ, 2013; MoEn, 2015), while the proportion of PV was expected to account for only 8.5% of the total electricity capacity. Unfortunately, the actual capacity of the solar farm through the grid system by the end of 2014 was only 1,298.51 MWp or 2.6 % of the total capacity, while the actual capacity from the PV through the off-grid system, previously emerged independently at the niche level, contributed to just only 43 MWp (DEDE,

2014). The dominant PV systems in Thailand, initiated by the government to support the structuration of activities according to the MLP concept, was quite minimal.

In 2008, the impact of subprime mortgage crisis changed the situation of PV. Global demands, especially in the US and Europe, on renewable energy and PV decreased (Wiser, 2008). The prices of equipment for PV decreased considerably in manufacturing costs from major PV producers, in particular, China (Feldman et al., 2012). This, in turn, opened opportunities for solar businesses to grow including those in Thailand (Tongsopit, 2015).

2.2 Science and technology related to PV

In the beginning, the off-grid system in the remote areas was installed using the western technology with limited experience which was later proved ineffective. By the end of the 1990s and in 2000s, the PV technology in Thailand began to develop from the original western knowledge through efforts of technocrats and academics. There were three stages of development. The first stage was both research and application of the PV stand-alone and PV hybrid system that increased technology maturation combining many systems that were more complicated than the off-grid/stand-alone system.

The second stage was a demonstration of the PV grid-connected system in forms of solar rooftop in the urban area which started in 2002. This was the beginning stage of the PV grid-connected system.

The third stage was concerned with PV power plants as solar farms connected to grid lines. Currently, PV panel technology and Balance of System (BOS) equipment have been developed economically for more reliability and accuracy. This innovation has to be in line with the EGAT's regulation on the circuit discharge.

In addition, universities and academic institutes conducted research and development on solar cell fabrication. Later, National Science and Technology Development Agency tried to develop thin-filmed silicon cells in various methods. Furthermore, there were studies on nanotechnology in the electron injection process or dye-sensitized solar cell as alternative and more cost-effective approaches. However, these Thai R&Ds have been developed up to only at the laboratory level long, waiting for commercial production by Thai PV industries.

Table 1 Substantive analysis of the regime under the MLP framework

Landscape Change / Structuration of activities	Before 1970	1990 - 2005	1990 - present	
	Cold war: US assistance	Oil and monetary crisis	Global warming and environmental awareness	
Politics	**Military regime**	**Semi-democracy**	**Polico-business**	**Politics in transition toward the national reform**
Policy and implication	- Economic development toward industrialization - Construction of fossil-based power generation and distribution by state enterprises	- Adding hydropower as a supplement - Shifting to natural gas as main energy for expansion of power generation	- First launching ineffective solar home systems in rural area from populism policy - Privatizing state enterprise energy - Beginning independent small and very small private fossil-based and renewable power producers under control and monopolized distribution by the regime	-Maintaining supply power from diversified sources of energy and products from private producers - Remaining control and monopoly of fossil-based power and distribution by the regime

Table 1 (Cont.)

Landscape Change / Structuration of activities	Before 1970	1990 – 2005	1990 – present	
	Cold war: US assistance	Oil and monetary crisis	Global warming and environmental awareness	
Politics	**Military regime**	**Semi-democracy**	**Polico-business**	**Politics in transition toward the national reform**
		- Extending economic growth outside Bangkok through accreted rural electrification	- Initiating a reform of energy from the concession of natural gas and starting up alternative energy for power as a response to environmental activities	
Science and Technology	- Importing thermal power plant technology and western trained power engineering technocrats	- Relying more on hydro and gas for power generation technology and manpower	- Advanced technology, equipment and power engineers on hydro, gas and pollution reduction from developed countries - Small opportunity and supports started academic research and experiments on solar and hybrid system power generation	
Industry	- No domestic industries for thermal power plant equipment nor electrical appliances - The beginning of exported electrical appliances	- The non-existence of domestic industries on generating and distribution equipment - A great expansion of foreign investment and manufacturing of electrical appliances in the country	- Accessories and parts for power generating and distributing produced domestically - Extensive supplies of basic and advanced electrical appliances produced domestically as branches of transnational companies	
Market	- Supplies on power and electrical applies' beginning to induce demands of urban users	- Availability of power and supplies of electrical appliances nationwide	- Full-fledged production of transnational electrical appliance's meeting growth home and industrial uses	
Socio-culture	- Power as a driving force for economic and luxurious urban people	- Electricity as an imported input for urban and rural economic activities and basic necessity for livelihood	- Awareness of environment affected by fossil-based power production by some activities but with a limited option on alternative sources - Electricity regardless of energy sources still required by the majority	
Characteristics of the regime	- Strong establishment of Thai electricity for economic development using foreign technology, operated and monopolistically controlled production and distributions by state enterprises	- Expansion of fossil-based power generation (on gas) and distribution serving nationwide economic and user demand - Power stabilized under controlled and becoming a regime	- Diversity in a fossil-based generation by supporting private producers, energy monopolized by a privatized company, and all power and distribution controlled by the regime - The regime confronted by environmental activities and uncertainty of gas: beginning to adapt itself to maintain stability and opening opportunity for alternative sources	- Diversity in fossil-based energy production and resource by supporting alternative energy continued - The start of the regime's reform with a natural gas recession by claiming its stability and reliability of power
	- Electric power industry is viewed as a monopoly, heavily regulated, price controls and government-owned and operated.			

Sources of data for analyses of Table 1: documents, statistics, key actor interviews from a mixed-method

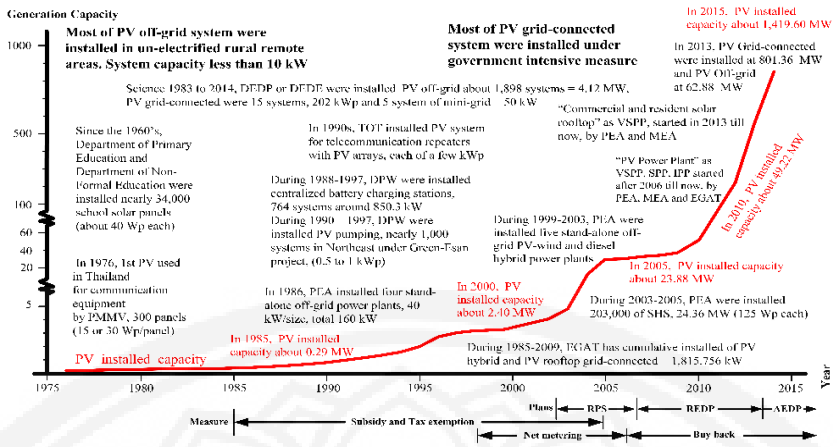

Figure 2 The development of the photovoltaic system in Thailand

2.3 Market and industry of PV

In the beginning, the market for PV appliances and accessories was very small. In order to stimulate the market and make rural off-grid PV programs possible, agencies subsidized all costs for users. At that time, almost all PV modules and BOS were imported (Kirtikara, 1997; MoEn, 2014). Later, the Thai company named LEONICS was the only one prominent company manufacturing BOS of charge controllers and inverters.

In 2004 when the PV off-grid system, especially the Solar Home System (SHS), was introduced starting from the government-subsidized mega projects, demands for PV components rose. Consequently, there were five companies manufacturing solar panels while PV production machines were imported (Kaunmuang, 2006). In addition, two telecommunication business companies joined the market but later all types of equipment except batteries discontinued because of the termination of the government's SHS programs.

During the period between 2002 and 2004, the demonstration of the solar rooftop as the grid-connected PV system was introduced by Energy Planning and Policy Office (EPPO). The government's subsidy for PV changed from previously 100 % on the off-grid PV system to agencies and users to 46 % on the grid-connected solar rooftop to private and users. However, the market grew slowly and later discontinued because of the inappropriate local BOS technology.

The domestic PV market appeared to grow as an impact of the grid-connected system starting in 2006. In particular, there were several private power producers investing in solar farms and large-scaled solar rooftops, generating electricity connecting to grid lines, benefiting from ADDER, and replacing monetary subsidization as incentive measures. At present, the industries producing the main parts of PV equipment and materials have been established, but the PV supply chain for producing the detailed equipment for the entire system has not been completed yet. Currently, the PV off-grid system has an insufficient number of business sectors to support the entire PV operation and maintenance system. On the other hand, the PV grid-connected system is rapidly growing and is fully supported by related businesses, but they have been thriving under a strict control by the electricity regime.

2.4 Socio-culture of PV systems

The PV off-grid system was provided in remote areas by the government's energy promotion agencies to provide equal opportunity for accessing electricity. In the early days, those energy agencies had no experience in

the PV off-grid system and the malfunctioning of the system was due to a lack of adequate user's knowledge (Kaunmuang, Kirtikara, Songprakorb, Thepa, & Suwannakum, 2001). Even though there were research studies claiming that this system could increase the standard of living and promote environmentally friendly technologies (Green, 2004; Thanarak, Schmid, Wattanapong, Chaowakul, & Yammen, 2006), the rural area had many limitations for PV installation, application, and maintenance which unenviably caused a system failure (Kaunmuang et al., 2001).

While PV off-grid users had high expectation but several variables did not support their future use such as a high investment, the inappropriate environment of the location which affected BOS, and a lack of operating and monitoring system by responsible agencies. The users in rural areas accepted the PV off-grid system because they had no choice. In addition, the community could not solve problems concerned with the PV off-grid system in the long run.

In terms of the PV grid-connected system, the cheaper price of solar cells and credits from the financial sector for investment have caused a rapid increase in installing the system. To investors, an electricity business with a solar farm is a worthy, low-risk economic return since contract parties are the government agencies. These investors expect an economic return more than environmental conservation.

There are successful for grid-connected system and can generate high electricity load but users cannot classify the source of energy, while environmental awareness among users and the public sphere has started and acted against polluting energy but seemed unclear about alternative green energy, especially PV.

2.5 Characteristics of Thai PV systems as an experiment

From the MLP perspective, we found that the landscape change resulting from the oil crisis was a major turning point to incorporate renewable energy in the National Economic and Social Development Plan. In the early stage, PV applications were off-grid units in rural remote areas. The system design was from technocrats within the electricity regime, rather than local initiatives.

Later on, the SHS project was the populism policy that distributed off-grid line electricity covering the areas with no electricity access and stimulated the emergence of the solar industry, but the PV off-grid business scheme did not grow and ceased after the government ended the funding. The maintenance problem remained as users were unskilled for managing and maintaining the system.

Environmental awareness became significant after the beginning of the 21st century and there was pressure on the Thai government and the electricity regime to open an opportunity to develop renewable energy and the PV grid-connected system. The structuration of PV grid-connected activities seems to be a part of the existing electricity regime and all of the elements can be shared within the existing regime, whereas domestic entrepreneurs of PV module and BOS compete on price with other countries following market mechanisms. However, the development of PV in reserving energy still struggles as it cannot offer a real solution for the period of low sun lighting.

The MLP framework and empirical data presented above provide good explanations and give a reasonable answer to the challenges addressed earlier, particularly the possibility of PV's becoming a trajectory pathway for the energy transition, running in parallel as alternative power in the interaction of socio-technical regime with changes

through the structuration of activities. Likewise, the emergence, development, and struggle of the PV systems under both adaptations from the socio-technical regime and the recent environmentalism can be clearly seen through the structuration of activities at the niche level. All of these are summarized in Table 2

Discussion

As the demand of energy increased, the Thai electricity regime became stronger and the position of the main suppliers and distributors in the market became fortified. It turned into the socio-technical regime with major factors according to explanations from the MLP framework as follows: science and technology, governance, industry, markets and businesses, a culture of the users, and a supportive landscape. However, one of the interesting findings for the case of the Thai electricity regime was the fact that, among all internal factors, the coalition among politicians, bureaucrats, and technocrats appears to be the most determining factor shaping the characteristics and roles of the system. The Thai electricity regime has undergone the stage of turbulence (for example, oil crisis between the 1970s and the 1990s) and windows of opportunity would be opening again for an experiment to adapt to a new global warming situation of the 21st century, but PV in Thailand has not been developed according to the MLP framework. All of these can be summarized in Figure 3

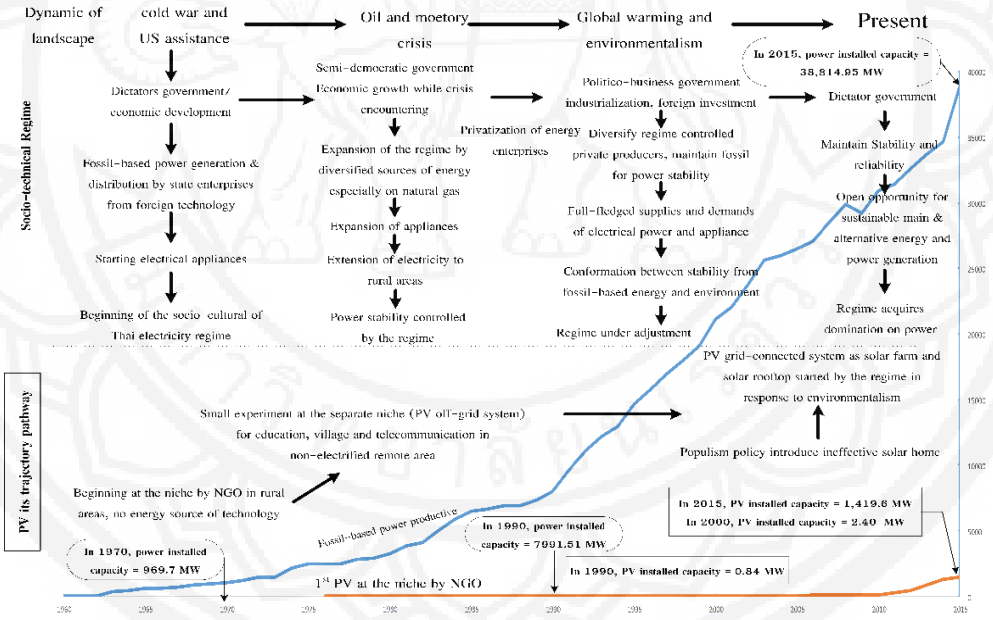

Figure 3 PV development and its struggle in transition

The external pressure from landscape changes coupled with an internal pressure as a political change toward politico business and social movement have forced the regime to adapt itself for a new situation. In fact, relying on fossil-based energy caused instability in the long run. PV, as an environmentally friendly alternative energy, has not been fully developed to replace the existing regime, since it lacks the government's support for development for

higher efficiency and reliability. However, the higher purchase price for the PV systems could impact the revenue of EGAT, MEA, and PEA in the long run.

Therefore, Thai electricity as the regime can be characterized as follows: a) fossil-based with imported knowledge and technology, b) manipulated by politics, bureaucracy, and technocracy which is centralized and monopolistic in nature, c) fully extended to accommodate people's needs in terms of market, and d) oriented toward the discourse of electricity reliability and stability.

PV was originally used as an off-grid, stand-alone system that was developed locally and independently from the government initiative and landscape changes with imported technology, or it was in a state of niche incubation. Later on, under the politico-business politics, the government promoted solar home systems as a populism policy. The initial stages of PV usage were eventually discontinued.

As mentioned earlier, the PV grid-connected system is based on both imported technology and government subsidy and has grown quite rapidly. Unlike the case of the regime, industry and market chains supporting PV has had only minimal growth. The nature of PV development can be concluded as follows: a) a niche development for the off-grid system which began at the initial stage but was later discontinued, b) a part of the regime adaptation for the grid-connected system, and c) absent for other structuration elements supporting the PV experiment at the niche level. Therefore, based on the MLP framework and empirical evidence, if the nature of PV development remains the same, the trajectory pathway of PV toward innovation transition for Thailand's electrical power is unclear.

The MLP concept was originated in Europe and it is based on socio-technical contexts of developed countries, the challenge is whether the trajectory pathways can be applied to developing countries. There have been some studies in India and Thailand focusing on mobility transition. This study, therefore, was the first attempt to analyze PV as an alternative electricity platform and its potential for becoming the trajectory pathway in Thailand. The results are at least the initial benchmark for further study even though there are no previous studies to compare.

By and large, this study encompassed the holistic, yet complex and dynamic, of two large systems, that is, the Thai electricity regime and the PV system. No developed methodology can capture such complexity. Therefore, future studies should focus on one system at a time. The comparison of the result can provide a more preside precise analysis and impacts on policies concerned.

Conclusion

The case of PV development and its struggle in the transition to become an alternative source of power to the dominant fossil-based Thai electricity regime may provide some contributions to the MLP framework under the innovation transition theory.

Firstly, according to the theory, the experiment emerges independently at the micro or niche level when the existing regime faces instability; and the experiment develops further gaining its momentum through the advancement of technology and markets become more supportive; the possibility for innovation transition is evident with its clear trajectory pathway (Geels, 2005). Emergence and development of the Thai PV appear not to quite conform to those theoretical conditions. This raises the questions of whether the MLP may explain better in the context of western

countries more than that of developing countries. Logically, almost all conditions for the experiment to become a potential innovation transition can happen only if the recipient of the innovation emerges and becomes mature in the developed countries. MLP, in order to have a more powerful explanation, may have to include a global interaction between developed and developing countries in the areas of novelty and international market in the analytical framework.

Secondly, as mentioned earlier, Thai PV has been the result of the regime adaptation to sustain its stability and respond to the pressure from environmentalism under the power of Thai politics, bureaucracy, and technocracy. This further suggests that the MLP framework in the developing countries may have to emphasize on the power of the political system since politics, more or less, is the most important determinant obstructing an experiment at the niche level.

Finally, for Thailand, the possibility of developing PV to become the real alternative to the existing fossil-based electricity generation depends on the following conditions: 1) political and energy reforms to increase and materialize active roles and power of the middle class and public as well as decentralization of governance, 2) technological breakthrough, which is more likely to succeed in the countries with advanced science and technology, to make Thai PV benefit not only in the novelty but also in supporting industries, businesses, and preferences of the mass users.

Table 2 Substantive analysis of PV systems under the MLP framework

Landscape Change / Structuration of activities	Before 1990	1990-2005	After 2005 – present
	Oil crisis and monetary crisis	Global warming, environmental awareness, and economic crisis	
Politics	Semi-democracy	Polico-business	Polico-business shift to politics in transition toward the national reform
Policy and implication	-Alternative energy initiative and PV studies and national plan started	-SHS project as political propaganda to gain votes received the highest public approval rating with no long-term development plan	-PV grid-connected system as a solar farm and a solar rooftop promoted via several plans and incentive measure under SPP programs
Science and Technology	-PV technology *found* attractive among academics and private sectors with limited supports	-PV hybrid off-grid and PV grid-connected systems as power plants and rooftops applied by government agencies -BOS equipment to be more reliable, accurate, and economical	- Organic dye-sensitized solar cell which is cheaper in progress but not widely used and not supportive of the current market. -Minor research in PV components and PV module accessories -Most of operating PV modules imported
Industry	-Almost all except two module assemblies produced abroad	-As a result of SHS populism policy, solar module manufacturers established and SHS inverter with a temporary particular processing line	-Manufacturers' competing in price and product quality with products from other countries -Industries related to PV developed but PV supply chain not yet completed
Market	-Subsidies on all costs for users by government agencies, funding for PV projects mostly from the annual government budget -Only PV off-grid accessory on market for rural users	-Government agencies subsidized partly cost for users -Solar energy markets dependent on the demand of a government agencies and policy -No PV business schemes supported in rural areas	-PV development as Consumer Market shifted from off-grid to grid-connected systems -Rapidly increasing demand for solar modules and BOS -Thai PV suppliers' inability to compete with global prices, resulting in several imported suppliers including system equipment and installation

Table 2 (Cont.)

Landscape Change / Structuration of activities	Before 1990	1990-2005	After 2005 – present
	Oil crisis and monetary crisis	Global warming, environmental awareness, and economic crisis	
Politics	**Semi-democracy**	**Polico-business**	**Polico-business shift to politics in transition toward the national reform**
Socio-culture	-Almost all of the malfunctioning systems unable to be fixed by villagers	-High expectation from PV users who cannot incorporate the use into their everyday life because of a self-maintenance problem with no culture emerged	-Culture of PV off-grid system not emerging -Culture of PV grid-connected system emerging as investment culture -Users' failure to identify different sources of energy - Social movement's failing to push political policies
Characteristics of the PV as a niche	-Opportunity and equality of electricity access provided through PV systems to users who are extremely dependent on government support -PV systems developed like a niche in line with the MLP framework	- More role on PV scheme by the government but with un-continuity and non-clarity of government policies, obstructing PV development as a niche experiment	-Structuration elements supporting PV at the niche level being absent -The development of PV being under control of the regime that is a part of the regime adaptation

Sources of data for analyses of Table 2: documents, statistics, key actor interviews and case studies of PV from a mixed-method

References

Amornsakchai, S., Annez, P., Vongvisessomjai, S., Choowaew, S., TDRI, Kunurat, P., ...Watana, E. (2000). *Pak Mun Dam MeKong River Basin Thailand. Thailand: World Commission on Dams.* Retrieved from http://www2.centre-cired.fr/IMG/pdf/F8_PakMunDam.pdf

DEDE. (2014). *Annual report 2014.* Department of Alternative Energy Development and Efficiency, Ministry of Energy: Thailand.

Dulin, A., Franko, C., Heun, C., & Masterson, S. (2008). *Voices from the margin: Rasi Salai Dam. ESCR Mobilization Project, Committee of the Mun River Wetlands Conservation Network*, Peace and Human *Rights Center of Northeast Thailand.* Retrieved from www. internationalrivers. org/ sites/ default/ files/ attached-files/rasi_salai_report_ciee_english_smallfile.pdf

Eley, R., Grant, T., Kulinlina, A., & Sanseverino, A. (2008). *Two sides to every story: a case of environmental communication in Mae Moh, Thailand.* Retrieved from https://web.wpi.edu/Pubs/E-project/Available/E-project-030908-163940/unrestricted/MaeMoh-Thailand-C08.pdf

Elzen, B., & Wieczorek, A. (2005). Introduction transitions towards sustainability through system innovation. *Technological Forecasting and Social Change*, *72*(6), 651-661. Retrieved from http://www.science direct.com

EGAT (2018). Electricity Generation Authority of Thailand. *System Installed Generating Capacity*. Retrieved from https://www.egat.co.th/en/information/statistical-data?view=article&id=80

EPPO (2017). Energy Policy and Planning Office. Ministry of energy (2017) Table 5.2-2: *Power Generation Classified by Fuel Type*. Retrieved from http://www.eppo.go.th/index.php/th/energy-information/static-energy/static-electricity?orders[publishUp]=publishUp&issearch=1

Feldman, D., Barbose, G., Margolis, R., Wiser, R., Darghouth, N., & Goodrich, A (2012). *Photovoltaic (PV) Pricing trends: historical, recent, and near-term projections*. Retrieved from https://www.researchgate.net/publication/236425911_Photovoltaic_PV_Pricing_Trends_Historical_Recent_and_Near-Term_Projections

Forsyth, T. (2007). Are environmental social movements socially exclusive? a historical study from Thailand. *World Development, 35*(12), 2110-2130. https:// DOI: 10.1016/j.worlddev.2007.01.005

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case- study. *Research Policy*, *32,* 1257- 1274. Retrieved from http: / / www. science direct.com

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33,* 897- 920. Retrieved from http: / / www.sciencedirect.com

Geels, F. W. (2005a). The dynamic of transition in socio-technical system: a multi - level analysis of transition pathway from horse- drawn carriage to automobile (1860- 1930). *Technological Analysis & Strategic Management*, *17*(4), 445-476. Retrieved from http://www.sciencedirect.com

Geels, F. W. (2005b). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi- level perspective. *Technological Forecasting & Social Change*, *72,* 681- 696. Retrieved from http://www.sciencedirect.com

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399-417. Retrieved from http://www.sciencedirect.com

GIZ. (2013) *Thailand implements photovoltaic support programme and increases renewable energy targets.* Retrieved from http: / / weben. dede. go. th/ webmax/ content/ thailand- implements- photovoltaic- support-programme-and-increases-renewable-energy-targets

GIZ. (2015). Thailand Solar PV Policy Update. Retrieved from http: / / www. thai- german- cooperation. info/ admin/uploads/publication/373753e644b0343571c0a12d43a8fc1fen.pdf

Green, D. (2004). Thailand's solar white elephants: an analysis of 15 yr of solar battery charging programmes in northern Thailand. *Energy Policy*, *32,* 747-760. Retrieved from http://www.sciencedirect.com

Greenpeace. (2015). *Krabi at the crossroads: dirty coal vs. clean renewable energy*. Retrieved from http://www.greenpeace.org/seasia/th/press/reports/Krabi-at-the-Crossroads

HPEA. (2015). *History of provincial electricity authority*. Retrieved from http: / / www. pea. co. th/ introduction /Pages/Introduction_014.aspx

IEA (2015). *World energy outlook 2015*. Retrieved from https: / / www. iea. org/ Textbase/ npsum/ WEO2015 SUM.pdf

Jochen, M., & Bernhard, T. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy, 37,* 596-615. Retrieved from http://www.sciencedirect.com

Kaunmuang, P., Kirtikara, K., Songprakorb, R., Thepa, S., & Suwannakum, T. (2001). Assessment of photovoltaic pumping systems in Thailand-one decade experience. *Solar Energy Materials & Solar Cells, 67,* 529-534. Retrieved from http://www.sciencedirect.com

Kaunmuang, P. (2006) Growth of Photovoltaic Industry and Market in Thailand -A Case Study of Solartron PCL. Paper present at International Conference Record of the 2006. In *IEEE 4th World Conference on Photovoltaic Energy Conversion. 7 - 12 May 2006*, (pp 2540-2543). Waikoloa, Hawaii: USA.

Kirtikara, K. (1997). Photovoltaic applications in Thailand: twenty years of planning and experience. *Solar Energy Materials and Solar Cells*, *47,* 55-62. Retrieved from http://www.sciencedirect.com

Kirtikara, K. (2004). Lessons learnt from using PV stand-alone systems to provide a better quality of life for rural people. *Proceeding of Technical Digest of the International PVSEC-14*, Bangkok, Thailand. Retrieved from https: / / www. researchgate. net/ publication/ 228459567_Lessons_learnt_from_using_PV_standalone _systems_to_provide_a_better_quality_of_life_for_rural_people

Langculanon, S. (2009). *The Development and Political Role of Political Business Group in Thailand.* Public Administration, National Institute of Development Administration, Bangkok: Thailand.

MoEn. (2014). *Photovoltaic status report (2012-2013).* Thailand: Department of Alternative Energy Development and Efficiency. Retrieved from http: / / www. eri. chula. ac. th/ eri- main/ wp- content/ uploads/ 2015/09/PV-Status-Report-2012_2013.compressed.pdf

MoEN (2015). *Thailand Power Development Plan 2015-2036.* Thailand: Ministry of Energy. Retrieved from https://www.egat.co.th/en/images/about-egat/PDP2015_Eng.pdf

MoEN (2016). *Energy Statistics.* Thailand: Energy Policy and Planning Office, Ministry of Energy. Retrieved from http://www.eppo.go.th/info/5electricity_stat.htm

NESDP. (1977). *National Economic and Social Development Plan* (4th Ed.). Thailand: Office of the National Economic and Social Board. Retrieved from https: / / www. nesdb. go. th/ nesdb_en/ ewt_dl_link. php? nid=3779

Nykvist, B., & Whitmarsh, L. (2008). A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting & Social Change*, *75,* 1373-1387. Retrieved from http://www.sciencedirect.com

Pasuk, P., & Baker, C. (2004). *Thaksin: The business of politics in Thailand.* Chiang Mai: Silkworn Books.

Padmanabha, U. (1983). *The United States of America and Thai economic policy* (1960-1970). Department of International Relations, Graduate school, Chulalongkorn University.

Quang Cu Tran. (2013). *ASEN Guideline on Off-grid Rural Electrification Approaches. ASEN Centre for Energy.* Retrieved from https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/ASEAN_Guideline_on_ Off-grid_Rural_Electrification_Final.pdf

Rip, A., & Kemp, R. (1998). Technological change. In: S. Rayner & E. L. Malone (Eds.). *Human Choice and Climate Change* (pp. 327-399). Columbus: Batelle Press. Retrieved from http://kemp.unu-merit.nl/ Rip%20and%20Kemp.pdf

Sirasoontorn, P. (2004). *Privatisation, restructuring and regulation: electricity supply industry in Thailand.* Australia: The Australian National University.

Thanarak, P., Schmid, J., Wattanapong, R., Chaowakul, M., & Yammen, S. (2006). Economic evaluation of photovoltaic systems for rural electrification in Thailand. *International Journal of Renewable Energy*, *1*(2), 45-54. Retrieved from https://www.researchgate.net/profile/Suchart_Yammen/publication/266868234_Economic_Evaluation_of_Photovoltaic_Systems_for_Rural_Electrification_in_Thailand/links/549366370cf22d7925da3019/Economic-Evaluation-of-Photovoltaic-Systems-for-Rural-Electrification-in-Thailand.pdf

Tongsopit, S. (2015) *Lessons learned from Thailand's solar PV roadmap initiative*. Retrieved from http://thaisolarpvroadmap.org/wordpress/wp-content/uploads/2015/04/01-Lessons Learned-from-PV-Roadmap-Initiative-2.compressed.pdf

Verbong, G., & Geels, F. W. (2007). The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). *Energy Policy*, *35*(2), 1025-1037. Retrieved from http://www.sciencedirect.com

Wiser, R. (2008). *Global Photovoltaic Market Trend Analysis: Implications of the Financial Crisis. Consultants to the Center for Resource Solutions, Electricity Markets and Policy Group at Lawrence Berkeley National Laboratory.* Retrieved from http://www.efchina.org/Reports-en/reports-efchina-20090219-1-en