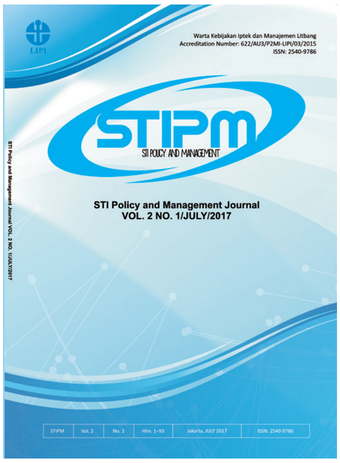

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Photovoltaic Development from the New Order Era to the Reform Era in Indonesia: From a Technological Innovation System Perspective

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FOREWORD by EDITOR-in-CHIEF

We are very pleased to inform readers that *Journal of Science, Technology and Innovation Policy and Management* (STIPM Journal) Vol. 2, No. 1, July 2017 is now ready for public reading.

The STIPM Journal is an online research journal managed by the Center for Science and Technology Development Studies at the Indonesian Institute of Sciences (PAPPIPTEK-LIPI). As a peer-reviewed journal, the STIPM Journal provides free access to research thoughts, innovation, and original discoveries mostly aimed at scholars.

In this edition, the STIPM Journal contains six articles dealing with science, technology and innovation policy and management written by scholars from Japan, Australia, and Indonesia.

The first article is entitled "Innovation Process of Natural Resource-based Firms in Four ASEAN Economies: A SEM Approach" by Masatsugu Tsuji, Hiroki Idota, Yasushi Ueki, and Teruyuki Bunno. Using a structural equation model (SEM), this paper discusses the innovation process in natural resource-based industries in Vietnam, Indonesia, the Philippines, and Thailand in comparison to other assembling and processing industries by focusing how factors affect product as well as process innovation.

The second article is written by Noel Taylor-Moore, entitled "The Innovative Policy Options for Coastal Fisheries Economic Development: A Case of Kwandang Bay Coastal Ecosystem". This article uses a policy innovation framework in the context of STI inputs and a multi-level perspective (MLP), selects a potential site in which a fisheries economic development hub would be implemented, and performs a SWOT analysis of the selected site as a hub.

Erman Aminullah, Trina Fizzanty, Karlina Sari, Rizka Rahmaida, and Qinan M. B. Soesanto present the third article, "Interactive Learning for Upgrading and Growth: Case of Indonesian Fishery Firms." This article discusses an interactive learning model for upgrading and growth in Indonesian fishery firms using the case of fish processing and aquaculture (shrimp). The model suggests that the dynamics of upgrading and growth through interactive learning will be able to continue in a stable manner as constraints from limiting elements are eased through: combating illegal fishing; encouraging interaction with universities; shifting to higher added-value products; increasing institutional support for global trading; preventing shrimp diseases; and providing infrastructure, business facilities, and regulation information.

The fourth article, entitled "Developing the Marine and Fisheries Industry in Pangandaran using a Bioecoregion-based Technopark Framework", is written by Atikah Nurhayati and Agus H. Purnomo. This article discusses how to establish a marine and fisheries technopark in Pangandaran. By using gap and SWOT analysis, it was found that particular recommendations for improvement should be made, the existing bioecoregional environment and development variables in Pangandaran would support the development of a marine and fisheries technopark.

The fifth article, entitled "Development of National Technology Audit Policy", is presented by Subiyanto. This article discusses the concept of a national technology auditing policy, particularly with regard to infrastructure requirements, and with emphasis on technical regulation effectiveness and implementation tool readiness. This article discusses setting a policy agenda by discussing the governance aspect of national technology auditing.

The final article is written by Anugerah Yuka Asmara and Toshio Mitsufuji with the title "Photovoltaic Development from the New Order Era to the Reform Era in Indonesia: From a Technological Innovation System Perspective". This article discusses the phenomena of PV development between the New Order era and the Reform era using a technological innovation system (TIS) approach. This paper concludes that PV projects and technology could not be developed en masse without intervention from the government in both the New Order era and the Reform era.

We also would like to thank the authors, editors, and reviewers who have worked very hard for this edition. We hope that all the articles featured in this edition proves useful to the reader.

Jakarta, 16 July 2017

Editor-in-Chief

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Photovoltaic Development from the New Order Era to the Reform Era in Indonesia: From a Technological Innovation System Perspective

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ABSTRACT

In Indonesia's New Order era, photovoltaic (PV) energy was introduced by the Indonesian government as a new and renewable energy (NRE). During this era, the directive in PV development was totally determined by the government. Afterwards, in the Reform era, there appeared a role for enterprises in PV development when the government issued regulations on the use of local products and the directorate of NREs at the Ministry of Energy and Mineral Resource was formed in 2010. To capture the phenomena of PV development between the New Order era and the Reform era, a technological innovation system (TIS) approach is used in this study. This study is a qualitative analysis using a case study method. The study finds that PV projects and its technology cannot be massively developed without intervention of government, both in New Order era and Reform era.

I. INTRODUCTION

Indonesia is located on the equator line and receives around 12 hours of sunlight a day (especially during the dry season). It has a photovoltaic (PV) energy potential of around 4,500–4,800 watt hour/m^2 per day and 2,000 hours per year (ESDM, 2012a; Solar energy, the industry, 2010). PV energy is important for Indonesia considering the country includes thousands of islands where supply of electricity supply is not abundantly available. Unfortunately, the government primarily depends on fossil fueled energy (i.e. coal and oil), while development of new and renewable energies (NREs) only emphasizes geothermal and hydropower power sources (PLN, n.d).

This is despite the government's introduction of PV energy in the 1970s, during the New Order era (Almanda, 1997). Government PV projects were first implemented in Indonesia in the 1980s, and many PV studies supporting PV projects in rural areas followed until 1997. PV projects were

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strongly supported by the Agency for the Assessment and Application of Technology (BPPT). During the New Order era, PV development was fluctuating and fickle. During the Reform era (beginning mid-1998), however, there was a vacuum in PV development until 2001, when it ran into significant growth following the Department of Energy and Mineral Resources and the state-owned electricity enterprise (PLN) decision to launch several PV projects.

PV development can be explained using historical events to describe how PV has grown or slumped during particular periods. Besides, PV technology trajectory is related to innovation systems involving many actors and institutions which influence its development (Huang & Wu, 2007; Lo, Wang & Huang, 2013). Later, Vasseur, Kamp, and Negro (2013) as well as Kebede, Mitsufuji, and Choi (2014) show that PV development in a country can be analyzed by using a technological innovation system (TIS) perspective. One of the main characteristics of TIS is the availability of function elements to map each of those functions for PV development in particular regions. In this study, the TIS perspective is used to describe PV development in the period from the New Order era to the Reform era in Indonesia.

In Indonesia, there have been many studies on PV energy and other related topics, such as the study titled *Off-grid photovoltaic application in Indonesia: An analysis of preliminary framework experience*, produced by Retnanestri, Outhred and Healy (2003). Other studies include those by Adityawan (2010); Silvi, Nurrisma, and Endarko (2013); Setiawan et al. (2014); Islamy and Sudrajad, (2014); and Sianipar (2015).

However, there are rarely studies on innovation systems in photovoltaic technology. Up to now, the researchers have not yet found a study which elaborates PV development with more detail into a historical framework of institutions, actors, networks, markets, policy, and PV technology in Indonesia. This study aims to find the 'drivers' and 'barriers' of function elements in PV development as well as to answer why they occur in Indonesia.

II. ANALYTICAL FRAMEWORK

A. Photovoltaics and PV Technology

A technology is a design for instrumental action that reduces the uncertainty in the cause-effect relationship involved in achieving a desired outcome (Roger, 1995). A technology usually has two components: i) a hardware aspect, consisting of the tool that embodies the technology as a material or physical object, and i) a software aspect, consisting of the information base for the tool (Roger, 1995).

In PV technology, PVs are electronic devices that convert sunlight directly into electricity. A PV system consists of PV cells that are grouped together to form a PV module, and the auxiliary components (i.e. balance of system (BOS)), including the inverter, controls, etc. (International Renewable Energy Agency, 2012). PV cell technologies are usually classified into three generations, depending on the basic material used and the level of commercial maturity:

1) First-generation PV systems (fully commercial) use the wafer-based crystalline silicon (c-Si) technology, either single-crystalline (sc-Si) or multi-crystalline (mc-Si). First-generation solar cells dominate the market with their low costs and the best commercially available efficiency.
2) Second-generation PV systems (early market deployment) are based on thin-film PV technologies and generally include amorphous silicon, cadmium telluride, copper-indium-selenide and copper indium-gallium-diselenide. Second-generation thin-film PV technologies are attractive because of their low material and manufacturing costs, but they have lower efficiencies than those obtained from first-generation technologies.
3) Third-generation PV systems include technologies such as concentrating PV (CPV) and organic PV cells that are still under demonstration or have not yet been widely commercialized, as well as novel concepts under development (International Renewable Energy Agency, 2012, pp. 4–6)

PVs have many benefits: it is available throughout the world; PV technologies are small and highly modular and can be used virtually anywhere; PVs have no fuel costs and relatively low operation and maintenance costs; PVs have a high coincidence with peak electricity demand driven by cooling in summer and year-round in hot countries (International Renewable Energy Agency, 2012). In the case of Indonesia, the majority of installed PV is classified as first PV generation (Ministry of Energy and Mineral Resources, 2012).

B. Technological Innovation System (TIS)

The technological innovation system (TIS) theory is rooted in the innovation system (IS) theory. Where the IS theory refers to the "incumbent technology" as the "regime", and "incubation rooms" for emerging technologies (the novelties) are labelled as "niches" (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007, p. 415). TIS looks at the network of actors, institutions (norms, regulations), and technologies that influence the development and diffusion of emerging particular technologies (Hekkert et al., 2007; Markard & Truffer, 2008; Markard, Stadelmann, & Trufer, 2009; Musiolik, Markard, & Hekkert, 2012).

In the TIS approach, innovations are related to the underlying technological base rather than to sectorial considerations or geographical boundaries. The functional TIS perspective, currently considered more appropriate for policy analysis than the structural view that characterizes the IS literature, allows a defining of systemic failures in the generation and of diffusion of a new technology in terms of problems or weaknesses in the key dynamic processes (functions) of an innovation system (Bleda & Rio, 2013). In the TIS approach, there are seven function elements that describe how a particular technology can develop well in a region or otherwise (see Table 1).

Each of the system functions can be fulfilled in away that can be either result in a positive (virtuous) or a negative (vicious) cycle. In the case of a virtuous cycle, the notion of cumulative causation suggests that system functions may reinforce each other over time—thereby resulting in a virtuous cycle. For example, the successful realization of a new technology starts with the guidance of the search (F4) as a 'motor', triggering and driving resource mobilization (F6), growing knowledge development (F2) and diffusion (F3), and then involving enterprises to materialize it (F1). Enterprises can increase lobby to stakeholders (F7) to create its market (F5) and back to formulate new regulations to reinforce the technology (F4). Conversely, system functions can hinder and stop a new technology if each of them is not positively integrated (Suurs &

Table 1.
Functions in a technological innovation system (TIS)

F1. Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative commercial experiments, seeing, and exploiting business opportunities.
F.2 Knowledge development	Technology research and development (R&D) are prerequisites for innovation. R&D activities are often performed by researchers, but contributions from other actors are also possible.
F.3 Knowledge diffusion	The typical organizational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange.
F.4 Guidance of the search	This system function represents the selection process that is necessary to facilitate a convergence in development, involving, for example, policy targets, outcomes of technical or economic studies and expectations about technological options.
F.5 Market formation	Now, technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow.
F.6 Resource mobilization	Financial, material, and human factors are necessary inputs for all innovation system developments, e.g. investments by venture capitalist or governmental support programs.
F.7 Creation of legitimacy	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology.

Source: Suurs & Hekkert, (2009a, p. 671, 2009b, p. 1005); Suurs, Hekkert, & Smits (2009, p. 9641); Suurs, Hekkert, Kieboom, & Smits (2010, p. 421).

Hekkert, 2009a, 2009b; Suurs, Hekkert, & Smits, 2009; Suurs, Hekkert, Kieboom, & Smits, 2010).

Limitations in the TIS Concept

A main limitation in TIS is that it tends to seize issues on the national level, while intertwined actors on the local level are also present (Markard, Hekkert, & Jacobsson, 2015; Coenen & Binzen in Bento & Fontes, 2015).

The concept of TIS has also received criticism from interdisciplinary scholars. Markard et al. (2015) describe six criticisms of TIS as follows: i) it is inward-oriented; ii) it tends to avoid the importance of external context structures; iii) geographical issues are not sufficiently covered; iv) the TIS framework is more useful as a framework for analyzing transition processes; v) it places politics in a marginal role; and vi) there may exist normative issues in the type of policy advice that follows from TIS analyses.

However, Markard et al. (2015) claim that TIS can be used in an analytical framework of actor connections, networks, and institutional structures. They argue that:

> "In our view, the TIS framework has the potential to address many of these issues. Its emphasis on the key role of different kinds of actors, networks, and institutional structures, together with its systemic approach, makes it possible to provide generalizable insights into a broad variety of change processes and also facilitates the connection to related strands of literature. TIS scholars have already begun to make these connections" (Markard et al., 2015, p. 84)

III. RESEARCH METHODOLOGY

This study uses the case study method, as presented by Yin (2003). A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life content. Case study is used in many situations to contribute to knowledge to our knowledge of individual, group, organizational, social, political, and related phenomena (Yin 2003, p. 1). A case study is used to cope with a technically distinctive situation (for instance, containing many interests) through multiple data sources, i.e. triangulation. Triangulation is an important way to elaborate and explain analyses results in more detail (Yin, 2003). Case studies are relevant to the TIS approach, and a method which integrates them can be used to explain how drivers of and barriers to photovoltaic development are present in Indonesia.

TIS in a context analysis of Indonesia's eras

Using a context of transition from the New Order era to the Reform era in Indonesia, TIS can delineate how related actors in the PV sector move and interact in a political and economic environment. The differences in institutional structures and government system in New Order and Reform era strongly influenced national PV development as approached by interest groups. In this matter, TIS functions to delineate and describe the changes in institutional structure and involved actors between the New Order era to the Reform era.

Therefore, TIS offers a holistic analysis of PV developments during the New Order and Reform eras—not only of the composition of actors involved in the growing national PV project, but also of supporting elements and the impact of institutional structures yielded by actors that appear in this context. The seven functions as outlined in Table 1 are present in a TIS analysis framework.

TIS is insightful in describing dynamics of national PV development between the 1970s and early 2015. TIS can be used to trace the history of PV and also recent state of PV technology in Indonesia. TIS is even useful for studying past events based on activities conducted by current actors involved in national PV projects.

In order for this study to make the best use of TIS analysis, it applies the event history analysis conducted by Suurs, et al. (2010). Several key practices of TIS study using historical events are as follows.

1) *Data collection*. Data were collected from both primary and secondary sources. Government documents and mass media publications regarding energy originating from the 1970s to early 2015 were compiled for this study. Experts were also consulted for this study.

2) *Database construction*. The collected data were arranged according to historical events. Texts, reports, laws were read and separated in order to be aligned with TIS framework.
3) *Event-mapping*. Each historical event was classified based on system functions (as provided in Table 1).
4) *Finding motors of innovation.* Interactions between system functions were sequentially traced from each found 'motor' at each period.
5) *Triangulation*. Historical events and their descriptions were arranged as objectively as possible. Consulting expert interpretation of these events by researchers was important for accurate narration and evidence purposes.

A TIS analysis framework specifically concerns related actors. This study will not use other analysis frameworks, such as the multi-level perspective (MLP) or the social construction of technology (ScoT). MLP, for example, as presented by Geels (2005) and Geels and Kemp (2007), tends to focus on the political and policy (actor-network) aspects in discussion. It is particularly more focused on how a new technology can emerge at the landscape level (i.e. received by the market) or why it is stagnant at the niche level (i.e. rejected by the market) through a perspective from the regime level (supporting policy elements).

Both MLP and TIS have similar main elements of focus, like emergence of actors, networks, and institutional structure. However, MLP is unable to describe the particular events that occur and their impact on the complete sequence of events influencing actors in different contexts, which TIS is able to describe at each period—such as in an entrepreneurial context, or a legitimacy context.

Therefore, TIS is this study's primary analysis framework for explaining the issues in each period of government. It is because this study focuses on the dynamics and history of technological change between the New Order and the Reform era. Furthermore, it needs a specific scope—namely, directly involved actors in national PV development. Historical events are a key element in this study, such that TIS is mainly used to analyze national PV development in Indonesia during the two eras.

IV. RESEARCH RESULTS

A. Historical Episodes of Photovoltaic Development in Indonesia

For this study, PV development in Indonesia is strictly divided into two government eras: New Order era and Reform era. During the New Order era, PV development system is split into three periods: 1970–1979; 1980–1990; and 1991–1998. During the Reform era, however, it is split into five: 1999–2001; 2002–2004; 2005–2009; 2010–2012; and 2013 onwards. Each of those periods is in turn divided into three sections: motor, structural drivers and barriers, and impact on TIS structure.

New Order era

In Indonesia, PV projects were introduced in the so-called New Order era, a period when Soeharto, an army general, led the Republic of Indonesia for 33 years from 1965 to 1998. In the politics and sociology field, this era was widely considered to be an authoritarian era as all programs were determined by the president.

1) Introduction of the first photovoltaics (1970–1979)

The Indonesian government introduced the concept of new and renewable energies (NREs) in the 1970s when an energy crisis occurred worldwide (Almanda, 1997).

a) Motor

Indonesians first used the solar home system (SHS), imported from foreign PV manufacturers, to fulfill electricity needs in several remote areas in 1970s *[F1-entrepreneurial activities]* (Witjaksana, 2005; Sumiarso, 2010).

b) Structural drivers and barriers

PV use was negligible in this period due to the 1970 soil boom around the world. Having been a member of the Organization of

Petroleum-Exporting Countries (OPEC) since Soekarno's Old Order regime (This is the story, 2015), Indonesia improved its export of crude oil in 1973–1974. Shortly after, Iran's revolution began, influencing the rising price of crude oil in the world (Keajaiban Orde Baru, n.d.). The Indonesian government had a surplus foreign exchange rate to defray the development of public infrastructure, including mining activities which generated fossil fuel energy.

c) Impact on TIS structure

The government prepared to arrange a national energy policy in 1976. However, it did allocate neither funds nor material to continue PV projects during this period. Due to the oil boom, all fossil fuel industries were built to achieve target of five-year development plan (REPELITA) period II (1974–1979) and III (1979–1984).

In early 1970s, Government of Indonesia was reluctant to develop alternative energies (including solar cell) because Indonesia had oil boom to defray infrastructures around Indonesia (See Table 2).

Table 2.
Drivers, Barriers, and Impact Underlying the Entrepreneurial motor in 1970–1979

	Actors	Institutions	Technologies
Drivers	Government introduced PV technology	First emergence of imported SHS	
Barriers	There were no governmental programs to continue PV projects	Oil boom, which Indonesia benefited from it	
Impact	Preparing to arrange a national energy policy		

2) Spearheading photovoltaic research and projects (1980–1990)

In the early 1980s, the global price of crude oil began to decrease (Keajaiban Orde Baru, n.d.). The government then remodeled energy policies to save and optimize energy use, including to develop new and renewable energies (NREs).

a) Motor

The National Energy Coordination Board (BAKOREN) issued the Public Sector Energy Policy (KUBE) in 1981. This policy was aimed at developing the intensification, diversification, and conservation of existing and potential non-oil energy (Direktorat SEMP-Bappenas, 2012). As a consequence, the government started developing NREs, including PVs, in Indonesia *[F4-guidance of the search]*.

b) Structural drivers and barriers

Based on KUBE 1981, the Agency for the Assessment and Application of Technology (BPPT) undertook a PV feasibility study using imported solar cells in the early 1980s *[F2-knowledge development]* (Layuck, 2003). In 1985, Lembaga Elektronika Nasional (LEN)[1] at the Indonesian Institute of Sciences (LIPI) conducted research on PV cells (Si) in Bandung City (Akhmad, 2014). However, the last studies were only at a laboratory stage.

Emergence of PV studies more or less inspired revision of KUBE 1981 into KUBE 1987 *[F4-guidance of the search]*. Based on KUBE 1987 and BPPT's PV study *[F2-knowledge development]*, a PV project was first started by the BPPT in 1987 in Sukatani village, Sukabumi, West Java, by installing 80 sets of imported solar home systems (SHS) with a capacity of 50 Wp each *[F1-entrepreneurial activities]* (Almanda, 1997). Up to 1990, the government funded BPPT projects that studied and installed SHS in rural areas (Akhmad, 2014). The BPPT was also supported by foreign donors, including AusAID, USAID, Novem, and the Bavarian State Matching Fund (Witjaksana, 2005). In practice, the BPPT collaborated with other departments, local governments, and non-government organizations (NGOs) to install SHS and train PV users in rural areas *[F3-knowledge diffusion; F6-resource mobilization]*.

During this period, the capacity of imported SHS ranged from 25 to 50 watts, so the capability to generate electricity power was very low (Kumara, 2010). PV projects heavily relied on governmental projects; these were free for locals, through grants (Witjaksana, 2005). Additionally,

Table 3.
Drivers, Barriers, and Impact Underlying the Guidance of the Search Stage in 1980–1990

	Actors	Institutions	Technologies
Drivers	Government first funded PV projects	Decreasing crude oil price	BPPT conducted PV feasibility study
	BPPT was an important player in installing PV	New regulations on NREs	LEN-LIPI studied PV technology development
		Emergence of foreign donors for PV projects	
Barriers	PLN and government prioritized fossil fuel energy	Governmental electricity subsidy for oil,fossil fuels	PV research was merely “laboratory study”
		PV technology was expensive	Only imported PVs
Impact	Many actors were not interested in developing PVs	Continuing governmental PV projects to install SHS	Involvement of R&D organizations in supporting PV

the government still subsidized the state-owned electricity enterprise (PLN) on fossil fuel energy to support the growth of new industries. PV energy was costly and not competitive with fossil fuel energy.

c) Impact on TIS structure

SHS was only used by a few people in villages where there was no PLN electricity grid. It was used to replace traditional lamps (such as lanterns) with electric lamps (Kumara, 2010). To support the BPPT, many R&D organizations and universities conducted PV small and medium scale studies. Unfortunately, private enterprises were reluctant to develop PV during this time.

3) Expansion of photovoltaic projects (1991–1998)

In early 1991, increasing negative effects of industrialization were detrimental to environment quality (Direktorat SEMP-Bappenas, 2012). Environmental problems increased motivation to use NREs during this period.

a) Motor

KUBE 1991 was renewed by the government to focus on the intensification, diversification, conservation of energy, as well as to reduce dependence on oil fuel as the main source of energy (Direktorat SEMP-Bappenas, 2012). Within KUBE 1991, there was “presidential support for rural electrification”, which promoted the implementation of PV projects, including the commission of a project to install 1 million SHS *[F4-guidance of the search]*.

b) Structural drivers and barriers

Justified on the basis of “presidential support for rural electrification”, the government funded 13,345 SHS installations in rural areas in 1991 (Nugraha, 2014), particularly in 15 of 27 provinces[2] in Indonesia. This move involved the BPPT, several departments (including public housing, public affairs, transmigration and village development), and local governments *[F6-resource mobilization]*. Additional support for PVs emerged after the government ratified the United Nations Framework Convention on Climate Change through Law No. 6/1994 *[F4-guidance of the search]*. Until 1994, the capacity of installed PVs was around 2.5–3 MWp in rural areas where there was no PLN grid *[F1-entrepreneurial activities]* (Almanda, 1997).

Later, the BPPT predicted that the needed capacity for PV-based electricity generators (*pembangkit listrik tenaga surya*, or PLTS) by 1994–2004 was 50 MWp–100 MWp*[F2 –knowledge development]* (Almanda, 1997). Following this study, NGOs and the government through the BPPT implemented 10,000 SHS units with a capacity of 48–55 Wp to fulfill electricity needs in rural areas, namely in Kentang Village, Gunung Kidul Regency, Yogyakarta, in 1995[3]*[F1 –entrepreneurial activities]* (Almanda, 1997). Funds were derived from *Bantuan Presiden*, a presidential grant, and foreign donors

[F6-resource mobilization] (Witjaksana, 2005). Additionally, all SHS units were imported from overseas PV manufacturers, and those were free for locals (Witjaksana, 2005).

With the aim of limiting imported PVs, new research on PVs, specifically on thin film a-Si, was introduced by Dr. Wilson Wenas from the Bandung Institute of Technology (ITB) in 1995 (Akhmad, 2014). ITB also developed solar cells with amorphous silicon using plasma technique to increase the efficiency of solar cells by 11% before degradation (Layuck, 2003). However, ITB's research did not reach the commercial stage due to minimal funding and lack of support from the government. Nevertheless, the government continued the 1-million, 50MWpSHS project by appointing PT LEN to produce and install SHS units in 1997 *[F6-resource mobilization]* (Ismet, Sopandi, & Sofyan, 1999). This was PT LEN's first national initiative to manufacture and assemble PV components *[F1-entrepreneurial activities]* (Setiawan et al., 2014). PT LEN even collaborated with Solarex-Australia (with a capacity of 3 MWp/year), who transferred PV battery and module technology *[F2-knowledge development; F3-knowledge diffusion]* (Ismet, Sopandi, & Sofyan, 1999).

Solar cells, a main part of the PV module, were still imported, and the government still subsidized PLN's use of fossil fuel energy. Consequently, the cost of PV production and maintenance was altogether more expensive than fossil fuels. Furthermore, the failure of PV projects was exacerbated by the financial crisis in 1997. The 1-million SHS project miss edits target (Witjaksana, 2005), and foreign grants and donations stopped. According to data from the Ministry of Energy and Mineral Resources, the total installed PV capacity in 1997 only reached 0.88 MW out of the targeted 1.2×10^9 MW (Widodo, Suryono, Tatyantoro, & Tugino, 2009).

c) Impact on TIS structure

Both PLN and private enterprises were reluctant to develop PVs in this situation. Therefore, the National Energy Coordination Board (BAKOREN) formulated the new KUBE 1998 to replace KUBE 1991; one of the new directives was the cutback of oil fuel as a main energy source (Direktorat SEMP-Bappenas, 2012). Unfortunately, this regulation could not be enforced due to the political and economic instability arising out of 1997.

Reform era

On 21 May 1998, Soeharto was replaced by Habibie as president, ending the New Order era and beginning the Reform era in Indonesia.

Table 4.
Drivers, Barriers, and Impact Underlying Guidance of the Search in 1991–1998

	Actors	Institutions	Technologies
Drivers	Government agencies supported PV projects in rural areas	Environmental deterioration	Emergence of PV studies
		New regulations supporting PV	PV technology transfer from Solarex (Australia) to PT LEN (Indonesia)
	BPPT implemented PV projects	Many government–al PV projects	
	PT LEN manufactured PVs	Foreign donors for PV projects	
Barriers	PLN prioritized fossil fuels as main energy	Governmental subsidy for use of oil-fueled electricity	Solar cells were imported from overseas
	Lack of PV awareness in some government agencies	Lack of funding and donors for PVs due to 1997 financial crisis	PV research did not reach commercial stage
Impact	PLN and private enterprises were reluctant to develop PV technology	KUBE 1998 regulations to create larger PV projects were not implemented	PV technology development was not optimal until 1998

Differing from the New Order era, the Reform era welcomed freedom of politics and opinion. The central government was no longer the sole decision-maker on development programs as local governments joined the table following decentralization. Additionally, mass media and new communities emerged, cultivating the democratic climate in Indonesia.

1) Vacuum in photovoltaic development (1999–2001)

Between 1998–2004, Indonesia changed presidents as many as three times with differing term lengths[4]: Habibie, 1998–1999; Abdurrahman Wahid, 1999–2001; and Megawati Soekarnoputri, 2001–2004. Habibie led a short term, so there was no significant change in NREs. Abdurrahman Wahid, however, often changed around his cabinet members, to the detriment of governmental programs.

Due to the uproarious political situation, the national economy had yet to recover from the financial crisis. In 1998–2002, national economy growth was about 2.3% annually (Regulation of the Minister of Energy and Mineral Resource No. 0983 K116/MEM/2004). During this period, neither the government nor the private sector paid PV projects any serious attention. However, in 2001, the World Bank launched its own PV program (Witjaksana, 2005).

Table. 5
Drivers, Barriers, and Impact in 1999–2001

Drivers	Actors	Institutions	Technologies
Barriers	Government did not have a program for NREs	Political and economic instability; no institution supporting PV projects	
Impact	New PV activity was absent	New foreign interest in PV beginning 2001	New PV technology was absent

2) Reemergence of photovoltaic projects (2002–2004)

In this period, the use of oil fuel was predicted to end in 10 years (Regulation of the Minister of Energy and Mineral Resource No. 0983 K116/MEM/2004). Also,the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002 encouraged the use of NREs in Indonesia. The Ministry of Energy and Mineral Resources[5] thus began to take a more active role in NRE development.

a) Motor

The Indonesian government issued Law No. 20/2002 on Electricity. Two purposes of this act were to implement NRE use and establish electricity grids in village areas. This regulation spurred Ministerial Decree of Energy and Mineral Resources No.1122K/30/MEM/2002 on Dispersed Small Scale Generators, which supports societal participation in the fulfillment of electricity needs with a capacity of less than 1 MW and to be covered by PLN's low-level electricity grid *[F4-guidance of the search]*.

b) Structural drivers and barriers

The Ministry of Energy and Mineral Resources issued National Energy Policy (KEN) 2003–2020 to replace KUBE 1998 (Direktorat SEMP–Bappenas, 2012). Referring to KEN 2003–2020[6], the Ministerial Decree of Energy and Mineral Resources No. 0002/2004 on Policy Development for NREs and Energy Conservation and Development of Green Energy was directed at NRE development, including PVs *[F4-guidance of the search]*.

To accommodate this regulation, the Ministry installed PVs with a 5-MW capacity in 2002 (Regulation of the Minister of Energy and Mineral Resource No. 0983 K116/MEM/2004) and launched the urban photovoltaic program in 2003. This program aimed to fulfill electricity needs at upper- and middle-class households, real estates, office buildings, industries, and so on (Sumiarso, 2010). Other ministries (i.e. public housing, public affairs, transmigration and village development) also carried out SHS installations *[F6-resource mobilization]*. However, each ministry implemented PV projects as mere governmental expenditure (Witjaksana, 2005), without coordination among themselves.

There existed a program led jointly by the BPPT and the World Bank to install SHS units[7].

SHS was subsidized by the World Bank by as much as US$2 per Wp, with a total subsidy of US$24 million for 200,000 SHS units, each having a capacity of 50 Wp (Witjaksana, 2005). The program ended in 2003 as the PV market was very limited. The governmental subsidy for fossil fuel energy was the main barrier—in 2002, the oil fuel subsidy covered about 36% of the oil fuel price (Regulation of the Minister of Energy and Mineral Resource No. 0983 K116/MEM/2004). PVs could not compete with oil fuel in price. The absence of PV dealers in several areas, the reliance of PV projects on government grants, and the low income of villagers were also barriers (Witjaksana, 2005). Technologically, PT LEN only assembled PV modules and its components; solar cells were imported. Furthermore, local PV technology development was conducted solely as an 'administrative routine', so new PV technologies did not appear.

c) Impact on TIS structure

PV development was not continued when Megawati's presidency ended in 2004. In Indonesia, the end of a president's term also means the end of all current ministerial offices, including their programs. Consequently, many private and state-owned enterprises were reluctant to develop PVs if there were no governmental PV projects. PV R&D activities were run without clear goals.

3) Photovoltaic projects on the road (2005–2009)

After Megawati, Susilo Bambang Yudhoyono (SBY) led the Indonesian presidency for two terms in succession (2004–2009 and 2009–2014).

a) Motor

The government issued Presidential Decree No. 5/2006 on National Energy Policy (KEN). KEN 2006 was implemented by launching the Blueprint on National Energy Management in the Period of 2006–2025 (Direktorat SEMP-Bappenas, 2012). Using the blueprint as a guide, the government set a target of 17% NREs out of total energy by 2025,with an emphasis of at least 5% biomass, nuclear, hydro power, PV, and wind power out of the total mix, or 800 MW with an annual growth rate of 40 MW until 2025 *[F4-guidance of the search]* (Development of energy......, 2014).

Table 6.
Drivers, Barriers, and Impact Underlying Guidance of the Search in 2002–2004

	Actors	Institutions	Technologies
Drivers	Ministry of Energy and Mineral Resources installed PVs Other ministries installed PVs PV donors emerged	International climate change agreements Predicted limited fossil fuel energy in the future New national energy law World Bank SHS programs	PV studies occurred
Barriers	No coordination among government actors in PV development State enterprises and PLN were reluctant on PV development PV donors left	Governmental subsidy for oil-fueled energy Unlike other NREs, PV development had no particular targets for even the next year PV price was not competitive to fossil fuel price World Bank's SHS program was ended in 2003	PV technology development was considered "administrative routine'
Impact	Actors stopped their PV projects	Directive to develop PV based on KUBE 2003–2020 was temporarily stopped	PV studies were run without clear goals

b) Structural drivers and barriers

Laws based on KEN 2006 were issued in support of NRE development, i.e.: Regulation of the Minister of Energy and Mineral Resources No. 002/2006; Regulation of the Minister of Energy and Mineral Resources No. 30/2006; Government Regulation No. 26/2006. In 2007, NRE development was given support in the newly issued Law No. 30/2007 on Energy *[F4-guidance of the search]*. Based on this law, in 2008 the president formed the National Energy Board (DEN) and the National Board for Climate Change to formulate and monitor the execution of KEN 2006, including the implementation of NREs. They functioned as a lobby in the House of Representatives (DPR) and other stakeholders for the development of all energy, including PV *[F7-creation of legitimacy]*.

PV projects were massively implemented on the issuance of Ministerial Decree of Energy and Mineral Resources No.2682 K/21/MEM/2008 on the National Public Plan for Electricity. Through this regulation, most villages received electricity in the next few years *[F4-guidance of the search]*, as SHS units with a capacity of 10 MW were installed to fulfill electricity needs in rural areas *[F6-resource mobilization]* (Kumara, 2010).

In 2009, the Government of Indonesia issued Law No. 30/ 2009 on Electricity Energy and Government Regulation No. 70/2009 on Energy Conservation, both supporting PV development *[F4-guidance of the search]*. To fulfill PV needs at a national scale, a private enterprise, PT SEI, was established. PT SEI is a subsidiary of PT LEN, with 90% of shares owned by PT LEN (Setiawan et al., 2014). The majority of governmental PV projects were carried out by PT SEI *[F1-entrepreneurial activities]*. In practice, SHS projects were developed not only by Ministry of Energy and Mineral Resources, but also by other ministries (i.e. public housing, public affairs, transmigration and village development) *[F6-resource mobilization]*. Unfortunately, PVs were considered as just "projects" (Witjaksana, 2005), and there was no coordination among them in its development.

Governmental PV projects were supported by research on PV battery standards conducted by the *Balai Besar Teknologi Energi* (B2TE) at the BPPT from 2006 to 2008 *[F2-knowledge development]* (Kumara, 2010). The research revealed that nearly 75% of all tested PV battery met the requirements to be able to be standard-certified properly (Kumara, 2010), but silicon and solar cells were still being imported from foreign PV enterprises. Another problem was that most PV technology was strictly laboratory-scale, and there was no integrated research to develop PV in this period. In terms of institutional barriers, PV energy was not a priority NRE, as opposed to geothermal and hydro energy.

After the World Bank's SHS program was ended in 2003, PV development met more obstacles, such as limited PV demand, no real incentives for investors, uncompetitive costs to invest PV infrastructure in rural areas, and the subsidy for oil-fueled energy (Sumiarso, 2010; Sumiarso, 2011). PV projects were given for free by the government to local people, who were not aware about PV capacity and PV maintenance. Banks or financial institutions also considered PV as not profitable goods. (Witjaksana, 2005).

c) Impact on TIS structure

PT LEN would begin building the first solar cell industry with a capacity of 50 MW under the direction of President Susilo Bambang Yudhoyono. PT LEN, together with Ministry of Research and Technology (Menristek), Agency for the Assessment and Application of Technology (BPPT), Ministry of Economy Affairs, Ministry of Energy and Mineral Resources, Agency for National Development Planning (Bappenas), Ministry of Marine Affairs and Fishery, Indonesian National Institute of Aeronautics and Space (LAPAN), and 20 other delegates formulated a roadmap and regulations for building a solar cell plant in Karawang, West Java, in 2010 (LEN, 2009). This program was related to the preparation of skilled human resources to work in the PV plant and collect many PV studies.

4) Emergence of photovoltaic enterprises (2010–2012)

In this period, PV growth significantly increased due to internal and external factors influencing its development.

Table 7.
Drivers, Barriers, and Impact Underlying Guidance of the search in 2005–2009

	Actors	Institutions	Technologies
Drivers	Ministry of Energy and Mineral Resources expanded SHS projects in rural areas Other ministries also installed SHS units PT SEI was built to manufacture PV	Creation of the National Energy Board and the National Climate Change Board New regulations produce blue print for PV development in 2006–2025	Testing of PV battery and PV feasibility study
Barriers	No coordination among government actors to implement PV projects Private enterprises and PLN were not interested in PV development Local people were unaware about PVs and PV maintenance	Governmental subsidy for oil fuel No large PV market PV energy was not a prioritized NRE Dependence on imported PVs Governmental project PVs were given for free	PV technology only at laboratory stage No integrated research for PV development
Impact	Increased coordination among government agencies and PT LEN in2010 solar cell plant construction	Formulation of roadmap and regulations for the 2010 solar cell plant construction	Collecting PV studies/research results to build 2010 solar cell plant

a) Motor

The Ministry of Energy and Mineral Resources[8] formed the Directorate General of New and Renewable Energy and Energy Conservation (Dirjen EBTKE)[9] on 14 April 2010. Dirjen EBTKE became the new first echelon at the Ministry of Energy and Mineral Resources, and was directly related to the Minister of Energy and Mineral Resources. Following the formation of the directorate, the 2025 target for the percentage of NREs in the energy mix was increased from 17% to 25% (Vision of Energy 25/25). In the same vision, the 2025 target for solar and wind energy was set at 0.6% *[F4-guidance of the search]* (Prawira, 2011).

b) Structural drivers and barriers

Another push that PV development in Indonesia received was from a meeting regarding national coordination on energy self-sufficiency and green economy improvement, attended by the President of Indonesia, the Ministry of Energy and Mineral Resources and DEN in Bali during 19–21 April 2010 *[F7-creation of legitimacy]* (Abdini & Adyawarma, 2010). Additionally, a meeting between the Ministry of Energy and Mineral Resources and the House of Representatives yielded six key PV policies concerning users, feed-in tariffs, technology audits, industry, 10-year targets, and R&D activities for PV technology *[F4-guidance of the search]* (7 key direction, 2010). To introduce these PV policies, Dirjen EBTKE did many supporting actions like promotion and exhibition of PV technologies to various stakeholders *[F3-knowledge diffusion]* (Dirjen EBTKE-EDSM, 2011).

To meet governmental PV project needs, as well as regulations promoting the use of local products, such as Government Regulation No. 4/2010 on the Appointment of PLN in Implementing the Acceleration of Development of Energy Generators Using New and Renewable Energy, Coal, and Gas, and Presidential Decree No. 54/2010 on the Procurement of Governmental Goods And Services, the Indonesian Solar Module Manufacturers Association (APAMSI) was established on 10 August 2010[10].

APAMSI's vision and mission demonstrate its role as a strategic government partner in the provision of PV products as well as in the education of local communities regarding the use of PVs *[F1-entrepreneurial activities; F3-knowledge* *diffusion]* (APAMSI, 2015). APAMSI's work was supported by Government Regulation No. 52/2011, which aimed to set aside allowances to electronic industries including those manufacturing silicon, ingot, and photovoltaic modules, and also by Regulation of the Minister of Industry No. 54/M-IND/PER/3/2012 to implement a set level of domestic products as percentage of content (*tingkat komponen dalam negeri*, or TKDN) in manufacturing PV components for solar home system (SHS) and centralised photovoltaic (PLTS). Based on the regulation, materials used in manufacturing SHS and PLTS are mostly made by domestic industry (national products). *[F5-market formation]*.

To bolster PV projects, the Ministry of Energy and Mineral Resources issued the National Electricity Public Plan for 2012–2031, which restricts the use of oil fuel as a main energy source for new electricity generators *[F4-guidance of the search]* (ESDM, 2012a). Cooperation between the Ministry of Energy and Mineral Resources, the Ministry of Industry, the Ministry of Cooperatives and Small and Medium Enterprises, the Bank of Indonesia, local governments, and APAMSI was intensified to expand PV projects *[F6-resources mobilization]* (ESDM, 2012a; Directorate of Informatics and Telematics, 2014). For instance, in 2012 Dirjen EBTKE appointed PT SEI and PT Bhakti Mukti (a local government-owned enterprise) to build the first two largest on-grid PLTS infrastructure, each having a capacity of 1 MW, in Bangli and Karang Asem Regency, Bali *[F1-entrepreneurial activities]* (Setiawan et al., 2014).

Meanwhile, PLN[11] together with APAMSI and PT INTI also built PV-based generators in remote, rural and frontier areas of business interest. Unfortunately, the construction projects by Dirjen EBTKE and PLN were run separately. Commonly, governmental PV projects were free for locals, but their low average education and excessive expectations of the PV-based generators were problems (Witjaksana, 2005). The other hindrance for the government was the subsidy for oil-fueled electricity (Sumiarso, 2011). The subsidy was significantly increased from Rp.140 billion in 2010 to Rp.256 billion in 2011, covering for more than 50% of the supply of oil-fueled energy (ESDM, 2012a). Consequently, the cost to build infrastructure for PV-based generators and transport them was very expensive and it remained an uncompetitive alternative to fossil fuel energy. Imported PVs were even cheaper than domestically made PVs, and the government's lacking performance in its role as a protector of national PV manufacturers became more apparent (Oemry, 2012).

Furthermore, based on data from the Ministry of Energy and Mineral Resources, there are quartz sand reserves totaling 17,491 billion tons[12] in Indonesia (Oemry, 2012). Yet although the BPPT had performed PV feasibility studies and drafted a roadmap for the development of crystalline technology (Akhmad, 2012), as well as collaborated with PLN to develop PV hybrid technology (Nugraha, 2014), the resulting research was not able to be commercialized into market. Lack of coordination among R&D actors and limited funding and R&D infrastructure were serious problems in the development of PV technology.

c) Impact on TIS structure

In the period of 2005–2011, energy supply from PLTS grids only reached 2.5 MWp/year in Indonesia (Akhmad, 2014). There remained little interest from business enterprises to invest in PLTS technologies in Indonesia. As a result, there was talk that "the richer they are, the higher the payout" for the PV tariff (Oemry, 2012). However, the government could have stipulated feed-in tariffs for national PV producers had they been ready to compete (Akhmad, 2012). On the technological side, PV R&D activities were prioritized to develop main solar cells. In this context, Agency for the Asssement and Application of Technology (BPPT) had developed newest PV technology of thin film (Low Solar Cell-Based Electricity Energy, 2012). Additionally, the Ministry of State-Owned Enterprises appointed PT LEN and Pertamina (state-owned oil and mining corporation) to build a solar plant in Karawang, West Java[13] (Pertamina, 2012).

Table 8.
Drivers, Barriers, and Impact Underlying Guidance of the Search in 2010–2012

	Actors	Institutions	Technologies
Drivers	Dirjen EBTKE led mass PLTS projects Emergence of APAMSI Ministries and local governments declared support for PLTS PLN builts PLTS projects as a business entity	Emergence of climate change as an issue Dirjen EBTKE focused on PV technology Use of TKDN for procurement of PLTS projects Roadmap of PV industry PV-lobbying activities	PV feasibility studies and roadmap were drafted Collaboration between BPPT and PLN to research hybrid PV Domestic reserves of quartz sand of up to 17,491 billion tons
Barriers	No coordination among government agencies to install PLTS projects Dirjen EBTKE and PLN built PLTS projects separately Locals were unable to maintain PLTS grids	Imported PVs were dominant Large subsidies for the use oil-fueled electricity Cost to build and maintain PLTS projects was not competitive with fossil energy Governmental PV projects were given for free	PV R&D was conducted by actors separately Lack of funds and facilities to develop PV technology PV technology remained at laboratory stage
Impact	PT LEN and Pertamina planned the construction of a solar plant	Stipulating feed-in tariffs for PV users and producers	Increasing R&D activity in the production of solar cell components

5) Creation of larger photovoltaic market (2013 onwards)

From 2013, PLTS projects saw increasing development under the government. During this period, the presidency transitioned from Susilo Bambang Yudhoyono to Joko Widodo in 2014.

a) Motor

The emergence of APAMSI was able to, more or less, influence Dirjen EBTKE to establish the PV market through Regulation of the Minister of Energy and Mineral Resources No.17/2013 on the Purchase of Electricity by PLN from PLTS *[F7-creation of legitimacy]*. The tariff amounts to US$0.25/kWh normally and US$0.30/kWh if the electricity provider uses local PV modules (i.e. at least a 40% TKDN, or 40% comprising of domestically made components) *[F5-market formation]*.

b) Structural drivers and barriers

The Ministry of Energy and Mineral Resources had established laws to promote feed-in tariffs for PLTS projects in remote and rural areas, i.e. off-grid and on-grid tied PLTS *[F4 – guidance of the search]* (Policy for the Implementation......., 2014). This was reinforced by Regulation of the Ministry of Finance No. 180/PMK.07/2013 on the Special Allocation Fund as well as Regulation of the Minister of Energy and Mineral Resources No. 03/2014 on the Technical Guide in Using the Special Allocation Budget on Rural Energy in 2014, which allocated funds to build PLTS projects in rural areas *[F6-resource mobilization]*. In 2013, the PLTS projects produced energy totaling 42.8 MW (3.0 MW on-grid and 39.8 MW off-grid) (Policy for the Implementation......, 2014).

In 2014, there were 130 centralized PLTS units (3,410 KW to 19,110 households) installed for free by Dirjen EBTKE in villages, border areas, and the outer islands of the country. This was achieved in cooperation with the Ministry of Marine Affairs and Fishery, the National Disaster Management Authority (BNPB), the Ministry of Defense, and local governments *[F6-resource mobilization]* (Development of energy......, 2014). SHS projects were also developed by other ministries (Public Housing, Public Affairs, Transmigration and Village Development). The Ministry of Industry in particular had a PV industry roadmap for 2011–2025 with regard to PV development (Directorate of Informatics and Telematics, 2014).

As a business enterprise, PLN utilizes feed-in tariffs to build PLTS projects– on-grid and off-grid. In the PLN plan, PLTS will be prioritized over SHS technology (starting with capacity from 632 MWp for both hybrid and independent-operated systems) in 1,000 outer and isolated islands[14]. Currently, PLN has built PLTS with an installed capacity of 12.1 Mwe, or 4.80 kWh/m^2 *[F1-entrepreneurial activities]*. PLN is to allocate a budget for PLTS construction of US$2853*,* though geothermal and hydropower sources remain PLN's focus for wide development (PLN, n.d).

On the technological side, the National Standardization Agency (BSN) has had an Indonesian National Standard (SNI) for photovoltaic module[15] since 2013 *[F5-market formation]* (Current Awareness Service Bulletin, 2013). Furthermore, many objects and products of PV research are well known, such as quartz sand, ingot silicon, solar cell 'wafers', and the like, but these technologies have remained prototypes or in laboratory stage. Most R&D organizations developing PV technology do not work in an integrated manner. For example, although PT LEN and Pertamina joined a consortium to construct a solar cell plant in 2012 (Akhmad, 2014)*,* the construction was only realized very recently.

An uncertain market is the main hindrance in developing the PLTS and PV industries in Indonesia (Center for Technology and Intellectual Property Rights, 2014). Between 2013 and 2014, Dirjen EBTKE auctioned only 8–10% of the 80 PLTS projects planned for construction in 2015 (Processing the potential, 2014). At PLN, fossil fuels were still largely subsidized by the government to use for energy: there was Rp.100 trillion (US$9 billion) set aside for oil-fueled electricity[16] in 2013, and Rp282.1 trillion (US$25.4 billion) for electricity and oil fuel in 2014 (International Institute for Sustainable Development, 2014).

On 17 October 2014, the Government of Indonesia released Government Regulation No. 79/2014 on the National Energy Policy (KEN), which replaced Government Regulation No. 5/2006. In this new regulation, the targeted energy mix of NREs is increased from 17% of total energy by 2025 to 23% of total energy by 2025 and 31% of total energy by 2050. Additionally, this law supports the PV industry ranging from upstream to downstream stages *[F4-guidance of the search]*. In 2015, the PLN established an export–import system[17] to receive excess electricity from PLTS and SHS units installed in private and government buildings *[F5-market formation]* (Solar Surya Indonesia, 2015). Again, the government planned to install solar panels in the presidential and House of Representative buildings (Said, 2015). While this may just be a symbolic program, it is aimed at encouraging a wider national PV market.

Nevertheless, there were many barriers that hinder PLTS units from becoming more competitive, i.e. pressure from cheaply imported PV modules, the lack of strong integration between Ministry of Energy and Mineral Resources, other government actors, and PLN in making PVs more affordable; low awareness among locals regarding PLTS maintenance; costly transportation and infrastructure in PLTS construction; the perception of PLTS projects as merely "governmental projects"; and the inconsistency of policy (lack of long-term fiscal policy) in PLTS expansion are the classic problems that must be solved by government.

c) Impact on TIS structure

To make PVs more competitive, many R&D activities are prioritized in order to reduce PV costs and develop solar cell technology (Ministry of Energy and Mineral Resources, 2012). BSN, Ministry of Energy and Mineral Resources, and Ministry of Industry consulted stakeholders and entrepreneurs regarding solar module standards before stipulating them as compulsive standards by 2016 (Policy for the Implementation......., 2014). To trigger the NRE market, the Ministry of Energy and Mineral Resources, through PLN, increased the electricity tariff for households with a capacity 1,300 VA or more. The tariff is based on market value, inflation, and the international oil price (Base electricity tarif, 2014; ESDM, 2012b). In June 2015, the level for the electricity tariff was increased from 220 KVA

Table 9.
Drivers, Barriers, and Impact Underlying Creation of Legitimacy 2013 onwards

	Actors	Institutions	Technologies
Drivers	Dirjen EBTKE collaborated with local governments and APAMSI to build PLTS and SHS projects PLN built PLTS units in rural areas Other ministries and local governments build SHS units	Feed-in tariffs established for PV investors SNI implemented for PV modules PLTS program for 1000 villages and outer islands Restrictions on oil fuel in building new electricity generator Special fund allocated by the Ministry of Finance to develop PLTS technology in rural areas Government Regulation No. 79/2014 (targeted NRE in energy mix is 31% of total energy in 2050) PV export–import system	PV potential is sought Many PV studies performed and technologies developed by R&D organizations
Barriers	Ministry of Energy and Mineral Resources and PLN build PLTS installations separately Weak integration between the Ministry of Energy and Mineral Resources, other ministries, and local governments in operating SHS/PLTS projects PLN focuses on geothermal and hydropower sourced–NREs only Low awareness and insight of locals regarding PLTS maintenance in rural and isolated areas	Uncertainties in national PLTS market Imported PV is dominant PLTS technology has a lower priority as an NRE source than geothermal and hydropower PV cost is not competitive with fossil energy Lack of long-term fiscal policy to develop PLTS Perception of PLTS as merely governmenttal projects (social aids)	Newest PV technology is merely prototype Local PV products are not competitive compared to imported PV PV research is conducted by R&D actors separately
Impact	Collaboration among government agencies to promote PVs and NREs by 2030 Ministry of Energy and Mineral Resources formulated derivative of Government Regulation No.79/ 2014	Electricity subsidy to be decreased incrementally PV export-import system of PV to be expanded Socialization of PV SNI	Prioritizing R&D to reduce price of PV production Developing upstream PV technology

(Tariff adjustment for non-subsidized, 2015). The implementation of a PV export–import system was to be expanded as well. Additionally, relating to Government Regulation No. 79/2014, the Ministry of Energy and Mineral Resources plans to formulate derivative rules for the execution of PV and NRE projects up to 2030.

V. DISCUSSION

A. Motor for entrepreneurial activities is initial photovoltaic development

PV development was introduced through the first PV projects during the New Order era (1970s) in Indonesia *[F1-entrepreneurial activities]*. However, PV entrepreneurial activities were not supported by governmental regulations. Due to the authoritarian nature of the period, government intervention was needed to implement any policies, including PV projects. Conversely, the government focused on mass development of the oil industry due to the global "oil boom" effect, which Indonesia benefited from. As a result, PV projects were negligible in 1970–1979.

B. Motor for guidance of the search is domination of photovoltaic development

After the oil boom effect decreased in the 1980s, the government began to pay attention to new and renewable energies (NREs), including PVs. In practice, PV development was dominantly triggered by governmental policies in both the authoritarian era (1980–1998) and the Reform era (2002–2012).Early in the Reform era (1999–2001), PV development was temporarily stopped due to political and economic instability.

In the New Order era (1980–1997), all PV projects were derived from government agencies. Particularly, the roles of BPPT and the Ministry of Research and Technology as led by Habibie[18] were dominant in influencing PV projects around Indonesia. Policy for science and technology development in Indonesia was Habibie's mission, supported by President Soeharto at the time. This 'guidance motor' had influenced four system functions (excepting market formation and creation of legitimacy) of PV development. The study identified structural drivers, barriers, and impact, discussed as follows.

The basis of the motor was formed by government direction that encouraged R&D organizations like BPPT, ITB, and LEN-LIPI to conduct PV studies and develop PV technology *[F2-knowledge development; F3-knowledge diffusion]*. The government devised new regulations and mobilized all resources to support PV promotion at the national level, including with regard to attracting foreign donors. Many governmental PV projects, with most being SHS projects, were implemented in rural areas, and in many of them the BPPT played a large role. PV studies by the BPPT were influential on such projects, which were then implemented by other departments and NGOs. In 1997, PT LEN as one of the state-owned enterprises, was assigned and funded by Government of Indonesia to run PV projects. To support this manufacturing process, BPPT, as a public R&D agency also collaborate with PT LEN in producing and implementing governmental PV projects.

The main structural barriers to the guidance motor were the oil boom and the role of the government itself. The government had at least two points of focus in national energy development. However, when the oil boom slowed in the 1980s, the government still paid total attention to oil-fueled energy to supply all national electricity need. As there were no large funds available to implement PV projects, subsidies for the use of oil fuel was unavoidable. All PV modules were still imported, and they were given for free to local people who did not have sufficient knowledge to maintain the technology. The impact was that the cost of PVs was not competitive with fossil fuels. Furthermore, many PV technologies remained at the laboratory stage (i.e. not commercial).

The striking impact of the ambiguity of the position taken by the government in developing national energy manifested in the reluctance of PLN and private enterprises to invest in PV projects. The government was the actor that determined which PV projects were implemented in Indonesia during the New Order era. When the 1997 financial crisis occurred, all PV projects and funding aids were stopped. However, PV studies were continued by separate actors at a small scale.

Meanwhile, PV development in the Reform era was also influenced by a guidance motor, particularly in the Megawati and the Susilo Bambang Yudhoyono presidencies. The emergence of climate change as an issue and thus the environment community was one of the main contributors of support to PV development during this period. On the ground, PV projects (SHS and PLTS) were installed by Dirjen EBTKE, PLN, other ministries, as well as local governments. During this period, all function elements were present excepting knowledge creation which only very minimally contributed to PV development. These elements reinforced each other in a virtuous cycle, in which the guidance motor was a primary key.

There were also several activities, pushed by the guidance motor, supporting PV development such as the creation of derivative regulations for near-future NRE target achievement. The derivative regulations were then adapted onto the ministry level. Among these, PV regulations by the Ministry of Energy and Mineral Resources were dominant. These regulations were adopted by PLN and other government bodies. There were also regulations created by other ministries which supported PV development *[F4-guidance of the search]*. Through such regulations, the Ministry of Energy and Mineral Resources and others mobilized resources to implement SHS and PLTS projects around Indonesia *[F6-resource mobilization]*.

When the Ministry of Energy and Mineral Resources launched SHS/PLTS projects and regulations, private enterprises (APAMSI) and state-owned enterprises (PLN) responded by installing PVs in rural areas *[F1-entrepreneurial activities; F5-market formation]*. Activities in PV development such as entrepreneurial actions and market formation influenced government bodies (the Ministry of Energy and Mineral Resources especially) to reformulate new regulations regarding PV technology. These regulations would guide other government actors, PLN, and APAMSI in developing PV projects later, including the development of PV technology by R&D actors.

In reality, PLTS technology was used on a limited scale (Center for Data and Information of Mineral Resource and Energy, 2012). After the World Bank stopped disbursing grants for PV development, the main structural barrier of the guidance motor was the expensive cost of building and maintaining PLTS technology, so that it was not able to compete with existing fossil fuel energy. Therefore, so it was difficult for the PV market to expand. There were at least four causes which made it difficult to commercialize local PV technology: large governmental subsidies for the use of oil-fueled energy; the lack of long-term fiscal policy to promote PLTS projects; the dominance of imported solar cell and PV modules (85% from China) (Sopandi, 2012); and that governmental PV projects were installed for free.

Weak coordination between Ministry of Energy and Mineral Resources, PLN, and other government agencies at developing PV projects was a problem hindering the mass installation of PLTS projects. On one hand, governmental PV projects made strong contributions to the wide development of PLTS. On the other hand, the dependence of PV development upon governmental PV projects could thwart its growth at the national level as locals did not have the readiness to maintain the PLTS technology installed. The seriousness of government support to PV development was questionable.

The impact of the guidance motor was different at each period. Generally, the Ministry of Energy and Mineral Resources and PLN continually improved coordination between various actors in the formulation of plans for and the implementation of PLTS. There were even plans to build a solar plant which were initiated by PT LEN and Pertamina in 2009 and 2012. Unfortunately, the efforts were not realized until the next period. It remains, however, that there was a resulting positive impact of this motor: the emergence of a PV industry roadmap and new regulations which supported local PV technology development.

C. Motor for creation of legitimacy to push PV market

The motor of legitimacy is the main trigger in the development of PV projects in the period of 2013 onwards (i.e. the late years of the Susilo Bambang Yudhoyono presidency to the current Joko Widodo presidency). Four element functions are present in this period (except knowledge development and knowledge diffusion). The emergence of APAMSI in 2010 significantly encouraged stakeholders (particularly the Ministry of Energy and Mineral Resources) to stimulate PV projects through the issuance of Regulation of the Minister of Energy and Mineral Resources No.17/2013 *[F7-creation of legitimacy]*. This regulation is expected to push the expansion of the PLTS market *[F5-market formation]*.

Structural drivers in PV market formation were supported by government interventions toward the achievement of PV targets *[F4-guidance of the search]*. Besides the Ministry of Energy and Mineral Resources, other ministries also mobilized resources to the cause, including funds, facilities and human resources *[F6-resource mobilization]*. Governmental PLTS projects are responded by private enterprises (APAMSI). APAMSI supports governmental PV projects based on the Decree of Minister of Industry No. 54/M-IND/PER/3/2012. In this project, APAMSI provides mostly local-manufactured PV materials.

In addition, PLN also built PLTS infrastructure as guided by its business interests and stipulated a PV export–import system*[F1 – entrepreneurial activities]*. The formation of a new market is apparent through the stipulation of SNI for PV modules *[F5-market formation]*, as well as the continuing development of PV research activities and diffusion. Governmental regulations are present to support existing PV phenomena. Sometime later, the Ministry of Energy and Mineral Resources and PLN promoted the new PV market and industry through Government Regulation No. 79/2014 *[F4-guidance of the search; F5-market formation]*.

Similar to the previous periods, the main barrier to PV development was market uncertainty. PLTS projects were dominated by the free governmental projects. Other hindrances to PV development were even derived from the government itself, like the subsidy for oil-fueled electricity. Dependence on fossil fuel took up an extremely high (nearly 95%) proportion of total energy in Indonesia (Direktorat SEMP-Bappenas, 2012). Again, weak coordination between government actors and PLN, the spread of imported PV, the prioritization of geothermal and hydropower sources as the main NRE sources, and the lack of long-term fiscal policy are key factors obstructing PV implementation originating from the government.

In 2014, the total capacity of installed PLTS was 27.23 MW domestically, less than 1% of total electricity potential, compared to 9.13% for hydropower and 17% for coal (Solar energy, the industry, 2010). This climate did not help domestic PV technology commercialize.

As a result, government intervention is actively needed to expand the PV market in order to reduce dependence on free governmental projects and to educate locals on PLTS maintenance. The government's target is growth of PV users and producers that is rooted in business enterprises (private and PLN), not from governmental projects. The Ministry of Energy and Mineral Resources is arranging a derivative of Government Regulation No. 79/2014 to support PVs in the future. With this, coordination between government actors should increase, and PV technology should be pushed into a commercial stage.

D. Strength and Limitation of TIS in the period of New Order dan Reformation Order

TIS is able to delineate how PV development in Indonesia transitioned from the New Order era to the Reform era. The dynamics of national PV development is explained through a sequence of historical events spanning from the 1970s to 2015. The motors that initiated PV development at each period have been identified, as well as the impact PV development had on the present motors (entrepreneurial activities, legitimacy, resource mobilization, knowledge creation and diffusion, market formation, and guidance of the search).

As described above, TIS functions to elaborate on the dynamics and transition of PV development from the New Order era to the Reform era. The involvement of entrepreneurial activities, governmental regulations and direction (guidance of the search), and legitimacy are the main elements that triggered PV development in Indonesia. For many years, PV projects were currently influenced by entrepreneurial activities and government policy. The two elements influence other elements which support PV projects in Indonesia.

TIS can answer why PV projects do not run well or even absent in any given time period in Indonesia, but are well developed in other periods. The results of this study can thus be used to formulate or reformulate policy related to PV development in Indonesia. From this paper, the Indonesian government can study how PV history (such as the motors and impact of PV development) unfolded in each different government era.

It would be beneficial for future decisions on how PV projects are to be developed, particularly in recent political conditions or even further in the future.

However, revelations regarding PV development and history through TIS are limited to a narrow scope, i.e. at the national level. National PV development was not separated from policy, norms, regulations, or interests of the local-level community. Again, the specificity of geographic areas in relation to support for PV development is less considered in this study.

The national context is dominant in this study—the TIS analysis framework focuses more on how national actors play their roles in the growth of PV projects in Indonesia. Many local actors who also contribute to national PV projects are over shadowed by the national context. Consequently, supporting elements of PV projects around Indonesia tend to appear in a national context and not in the context of specific geographic areas.

This study is based on a data compilation from primary and secondary sources. Secondary data is more dominant here than primary data as TIS analysis strongly relies on sequential historical data which describes the actors relevant to the development of PV projects in Indonesia. It is important to note that additional relevant data is needed to reinforce this study and its findings. Additionally, more primary data should be gathered to complement the secondary data in this study.

VI. CONCLUSION

From the New Order era to the Reform era, whatever kind of motor triggered PV development has strongly depended on governmental projects and regulations. In the New Order era, beginning in the 1970s, initial entrepreneurial activities relating to PVs were not continued as Indonesia benefited from the oil boom. Then, in 1980–1998, PV development strongly depended on direction from the central government. After the end of the New Order era, PV projects were temporarily stopped due to political and economic instability in the early Reform era (1999–2001). Following that, in 2002–2012, PV development continued with governmental guidance. From 2013 to recent years, the PV market is being pushed through many government policies. However, the findings of this study should be complemented by additional data, including finding the extent to which political factors can influence function elements in the development of PV technology in Indonesia.

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REFERENCES

7 key directions of the national energy policy. (2010, May 01). [*7 pokok arah kebijakan energy nasional*]. Okezone. Retrieved on 23 June 2015 from http://economy.okezone.com/read/2010/05/01/320/328236/7-pokok-arah-kebijakan-energi-nasional.

Abdini, C., & Adyawarma. (2010). *Paradigma iklim dan perubahan ekonomi hijau* [The climate paradigm and changes in the green economy]. Retrieved on 2 July 2015 from http://www.setneg.go.id/index.php?lang=en&option=com_content&task=view&id=5030.

Adityawan, E. (2010). A study of the characteristics of solar cell profiteering on the capacity of battery energy savings [*Studi karakteristik pencatutan solar cell terhadap kapasitas penyimpanan energy baterai*]. (Thesis). University of Indonesia. Retrieved from lib.ui.ac.id/file?file=digital/20249037-R031012.pdf .

Akhmad, K. (2012). Toward resilience in the solar cell and fuel cell industry[*Menuju kemandirian industri* solar cell *dan* fuel cell]. Retrieved on 11 June 2015 from http://tf.fti.itb.ac.id/2012/07/27/menuju-kemandirian-industri-solar-cell-dan-fuel-cell/.

Akhmad, K. (2014).Development of solar cell technology [*Perkembangan teknologi sel surya*]. Paper presented at the *Workshop for the Formulation of Priority Programs for the* R&D Industry, BPKIMI – Indonesian Ministry of Industry, Bandung, Indonesia.

Almanda, D. (1997). *Prospek PLTS di Indonesia* [Prospects for the solar cell generator in Indonesia]. Retrieved on 20 April 2015 from http://www.energi.lipi.go.id/utama.cgi?artikel&1065977402&11.

APAMSI. (2015). Profile of the Indonesian Association of Solar Module Manufacturers [*Profil APAMSI*]. Retrieved on 6 April 2015 from http://www.academia.edu/13217164/Asosiasi_Pabrikan_Modul_Surya_Indonesia.

Base electricity tariff increases, bitter gift from the start of 2015 [*TDL naik, kado pahit awal tahun 2015*]. (2014, December 15). RMOL.co. Retrieved on 18 May 2015 from http://www.rmol.co/read/2014/12/15/183389/TDL-Naik,-Kado-Pahit-Awal-Tahun-2015-.

Begini cerita Indonesia keluar dari OPEC tahun 2008. [This is the story of Indonesia's exit from OPEC in 2008]. (2015, September 9). *Tempo.co*. Retrieved on 5 November 2015 from https://m.tempo.co/read/news/2015/09/09/090699040/begini-cerita-indonesia-keluar-dari-opec-tahun-2008.

Bento, N., & Fontes, M. (2015). The construction of a new technological innovation system in a follower country: Wind energy in Portugal. *Technological Forecasting and Social Change*, *99*, 197–210. (https://doi.org/10.1016/j.techfore.2015.06.037).

Bleda, M., & Del Rio, P. (2013). The market failure and the systemic failure rationales in technological innovation systems. *Research policy*, *42*(5), 1039–1052. (https://doi.org/10.1016/j.respol.2013.02.008).

Center for Data and Information on Energy and Mineral Resources. (2012). *Indonesia energy outlook 2016: Energy development in supporting green industry* [Report]. Retrieved on 20 June 2015 from http://webcache.googleusercontent.com/search?q=cache:S9EB0V7dhEoJ:repositori.bppt.go.id/index.php%3Faction%3Ddownload%26dir%3D_data%252FDownload%252FOUTLOOK%2BENERGI%2B2016%26item%3DBPPT%2B-%2BOutlook%2BEnergi%2BIndonesia%2B2016.pdf%26order%3Dname%26srt%3Dyes%26lang%3Den+&cd=1&hl=en&ct=clnk&gl=id.

Center for Technology and Intellectual Property Rights. (2014, November). Conclusion of the *Workshop for the Formulation of Priority Programs for the R&D Industry,* Badan Pengkajian Kebijakan Iklim dan Mutu Industri, Ministry of Industry on 12–14 November 2014, Bandung, Indonesia.

Current Awareness Service Bulletin. (2013). *Standar menghadapi masyarakat ekonomi ASEAN.* [Standards in facing the ASEAN economic community]. *Current Awareness Service Bulletin, 1*(3)*,* i–30.

Development of energy and maritime-based mineral resources. (2014). *[Strategi pengembangan energy dan sumber daya mineral berbasis maritim].* Paper presented at the *Indonesian Maritime Congress*, Gadjah Mada University (UGM), held by Directorate of New and Renewable Energies – Ministry of Energy and Mineral Resource at Yogyakarta, Indonesia.

Dirjen EBTKE-ESDM. (2011). *Seminar & Exhibition Indo Solar–Wind 2011 11–12 May, 2011*. Retrieved on 15 June 2015 from http://ebtke.esdm.go.id/post/2011/05/11/6/seminar.dan.exibition.indo.solar.2011, (In Indonesian).

Directorate of Informatics and Telematics. (2014, November). Pengembangan industri fotovoltaik dalam negeri [Domestic photovoltaic industry development]. Paper presented at *the Solar Panel Workshop in Arion Swiss Bell Hotel Bandung,* held by Ministry of Industry at Republic of Indonesia, Bandung, Indonesia.

Direktorat SEMP-Bappenas. (2012). *Keselarasan kebijakan energi nasional dengan rencana umum energi nasional dan rencana umum energi daerah* [National energy policy accordance to national and local energy public plans]. Jakarta, Indonesia: Bappenas.

ESDM. (2012a). Energi baru terbarukan suatu kewajiban; Potensi besar energy alternatif. [Renewable energy a responsibility: The large potential of alternative energy]. *ESDM Magazine, 4*,17–19. Retrieved on 30 July 2015 from *http://prokum.esdm.go.id/ESDMMAG/ESDM%20Edisi%204.pdf.*

ESDM (2012b). Subsidi listrik tahun 2013 sebesar 78,63 triliun rupiah: Menurunkan beban subsidi. [Electricity subsidy in 2013 amounting to 78.63 trillion rupiah: Lowering the subsidy burden]. *ESDM Magazine, 7*,10–13. Retrieved on 30 July 2015 from http://prokum.esdm.go.id/ ESDMMAG/ESDM%20Edisi%207.pdf

Geels, F. W. (2005). Process and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change, 72*, 681–696.

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in society*, *29*(4), 441–455. (https://doi.org/10.1016/j.techsoc.2007.08.009).

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological forecasting and social change*, *74*(4), 413–432. (https://doi.org/10.1016/j.techfore.2006.03.002).

Huang, Y. H., & Wu, J. H. (2007). Technological system and renewable energy policy: A case study of solar photovoltaic in Taiwan. *Renewable and Sustainable Energy Reviews*, *11*(2), 345–356. (https://doi.org/10.1016/j.rser.2004.12.004).

International Institute for Sustainable Development. (2014). *Tinjauan subsidi energi di Indonesia* [A review of the energy subsidy in Indonesia]. *ISSD Edition, 1*(2),1–28.

International Renewable Energy Agency (IRENA). (2012). Renewable energy technologies: Cost analysis series, solar photovoltaics. *IRENA, 1*(5), 1–45.

Islamy, Z., & Sudrajad, A. (2014). Studi perencanaan atap panel surya di Hotel The Royale Krakatau Cilegon. [Study on the planning of the solar panel roof at the Royale Krakatau Hotel in Cilegon]. *Jurnal Energi dan Manufaktur, 7*, 119–224.

Ismet, I., Sopandi, A., & Sofyan, H. (1999). Fabrikasi modul surya dan peluang bisnis. [Fabrication of Solar Cell and Bussiness Opportunity]. *Proceeding of Pertemuan Ilmiah Ilmu Pengetahuan dan Teknologi Bahan 99*, p. 29–31, held in Serpong, South Tangerang, Indonesia on 19–20 October 1999.

Keajaiban Orde Baru Suharto di Indonesia [The miracle of Suharto's New Order in Indonesia]. n.d. *Indonesia Investments*. Retrieved on 25 August 2015 from http://www.indonesia-investments.com/id/budaya/ekonomi/keajaiban-orde-baru/item247.

Kebede, K. Y., Mitsufuji, T., & Choi, E. K. (2014). Looking for innovation system builders: A case of solar energy foundation in Ethiopia. *African Journal of Science, Technology, Innovation and Development*, *6*(4), 289–300. (http://dx.doi.org/10.1080/20421338.2014.947198).

Kumara, N. S. (2010). Pembangkit listrik tenaga surya skala rumah tangga urban dan ketersediaannya di Indonesia. [Solar electricity generators at the urban household scale and their availability in Indonesia]. *Teknologi Elektro, 9*, 68–75.

Layuck, J. R. (2003, December 20). *Wilson Wenas gelisah akan tragedi sel surya.* [Wilson Wenas worried for the solar cell tragedy]. *Kompas*. Retrieved from http://www.energi.lipi.go.id/utama.cgi?artikel&1080048809&10.

LEN. (2009). *LEN builds a 50MW solar cell industry* [*LEN bangun industri solar 50 MW*]. Retrieved on 29 June 2015 from http://www.alpensteel.com/article/115-102-energi-matahari--surya--solar/3029--len-bangun-industri-solar-cell.

Lo, C. C., Wang, C. H., & Huang, C. C. (2013). The national innovation system in the Taiwanese photovoltaic industry: A multiple stakeholder perspective. *Technological Forecasting and Social Change*, *80*(5), 893–906. (https://doi.org/10.1016/j.techfore.2012.08.016).

Low Solar Cell-Based Electricity Energy. (2012, June 3). *Listrik energi surya masih rendah. Antara Kalbar.* Retrieved on 20 August 2015 from *http://www.antarakalbar.com/berita/303195/listrik-energi-surya-masih-rendah.*

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research policy*, *37*(4), 596–615. (https://doi.org/10.1016/j.respol.2008.01.004).

Markard, J., Stadelmann, M., &Truffer, B. (2009). Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in Switzerland. *Research Policy*, *38*(4), 655–667. (https://doi.org/10.1016/j.respol.2009.01.013).

Markard, J., Hekkert, M., & Jacobsson, S. (2015). The technological innovation systems framework: Response to six criticisms. *Environmental Innovation and Societal Transitions*, *16*, 76–86. (https://doi.org/10.1016/j.eist.2015.07.006).

Ministry of Energy and Mineral Resources. (2012). *Matahari untuk PLTS di Indonesia*. [The sun for solar generators in Indonesia]. Retrieved on 3 July 2015 from http://www.esdm.go.id/berita/artikel/56-artikel/5797-matahari-untuk-plts-di-indonesia-.html.

Musiolik, J., Markard, J., &Hekkert, M. (2012). Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. *Technological Forecasting and Social Change*, *79*(6), 1032–1048. (https://doi.org/10.1016/j.techfore.2012.01.003).

Nugraha. (2014). Solar photovoltaic: As one of the energy solutions for Indonesia. *Handout of Presentation*. Jakarta: PT Wijaya Karya.

Oemry, A. (2012). *Menuju kemandirian industri solar cell dan fuel cell.* [Toward self-sufficiency in the solar cell and fuel cell industry]. Retrieved 10 July 2015 from http://tf.fti.itb.ac.id/2012/07/27/menuju-kemandirian-industri-solar-cell-dan-fuel-cell/.

Penyesuaian tariff listrik non subsidi per Juni 2015. [Tariff adjustment for non-subsidized electricity per June 2015]. (2015, June 5). *Tribun Lampung*, p. 7.

Pertamina. (2012). *Pertamina–LEN kembangkan industri solar PV.* [Pertamina-LEN develop the photovoltaic energy industry]. Retrieved on 10 August 2015 from http://www.pertamina.com/news-room/siaran-pers/arsip-2012/pertamina-len-kembangkan-industri-solar-photovoltaic-(pv)-potensi-permintaan-mencapai-65mwp-per-tahun/.

PLN. (n.d.). *Rencana usaha penyediaan tenaga listrik (RUPTL) PT PLN Persero 2013–2022* (RUPTL PT PLN 2013–2022) [PT PLN Persero Plan for the provision for electricity 2013–2022]. Retrieved from http://webcache.googleusercontent.com/search?q=cache:po9DjYCcnYEJ:www.djk.esdm.go.id/pdf/Coffee%2520Morning/Juli%25202016/Rencana%2520Usaha%2520Penyediaan%2520Tenaga%2520Listrik%2520(RUPTL)%25202016-2025%2520--%2520PLN.pdf+&cd=1&hl=en&ct=clnk&gl=id

Policy for the implementation of solar cell electricity generator. (2014). [*Kebijakan penerapan pembangkit listrik tenaga surya di Indonesia*]. Paper presented at the *Solar Panel Workshop and the Workshop for the Formulation of Priority Programs for the R&D Industry in the Electronics Sector*, held by Directorate of New and Renewable Energies – Ministry of Energy and Mineral Resource at Republic of Indonesia, Bandung, Indonesia.

Prawira, S. (2011). Indo solar conference & exhibition event – Wind 2011 [*Acara Seminar dan Exhibition Indo Solar – Wind 2011*]. Retrieved on 28 April 2015 from http://ebtke.esdm.go.id/post/2011/05/11/6/seminar.dan.exibition.indo.solar.2011.

Processing the potential of 11200 GWp with photovoltaics [*Olah potensi 11200 GWp dengan fotovoltaik*]. (2014). *mmIndustri*. Retrieved on 12 March 2015 from http://www.mmindustri.co.id/olah-potensi-112-000-gwp-dengan-fotovoltaik/.

Regulation of the Minister of Energy and Mineral Resource No. 0983 K116/MEM/2004. *Kebijakan Energi Nasional 2003–2020: Kebijakan energy yang terpadu untuk mendukung pembangunan nasional berkelanjutan (KEN 2003–2020)* [National Energy Policy 2003-2020: An integrated energy policy to promote sustainable national development]. Retrieved on 9 April 2015 from http://jdih.Energy and Mineral Resources.go.id/peraturan/kepmen-0983-2004.pdf.

Retnanestri, M., Outhred, H., & Healy, S. (2003). *Off-grid photovoltaic applications in Indonesia: An analysis of preliminary fieldwork experience* [Report]. Retrieved on 21 June 2015 from http://www.reee.sacities.net/sites/default/files/Tech%20Review/SOLAR/Case%20Studies/Off-grid%20Photovoltaic%20Applications%20in%20Indonesia-An%20Analysis%20of%20Preliminary%20Fieldwork%20Experience.pdf.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). New York: The Free Press.

Said, S. (2015, March 1). *Ini jadi simbol, Istana Presiden dan DPR bakal dipasang solar cell* [This has become a symbol, presidential palace and House of Representatives will be put solar cell]. Retrieved on 14 April 2015 from http://finance.detik.com/read/2015/03/01/172915/2846178/1034/jadi-simbol-istana-presiden-dan-dpr-bakal-dipasang-solar-cell.

Setiawan, S., Asmara, A. Y., Alamsyah, P., Maulana, Q. S. B., Manalu, R., Siahaan, S., & Pabeta, A. T. (2014). *Studi pada solar cell dan kapabilitas teknologinya menuju kemandirian energi* [Study on the solar cell and its technological capability toward energy self-sufficiency] [Unpublished report]. Jakarta, Indonesia: Pappiptek-LIPI.

Sianipar, W. (2015). *Centralised photovoltaic development policy in Indonesia.* Paper presented at the *Decentralised Photovoltaic Solar Power in Indonesia Seminar*, EKONID-eclareon GmbH in, Munchen, Germany.

Silvi, N. A., Nurrisma, P., & Endarko. (2013). Analisis perbandingan nilai efisiensi pada pembuatan *prototype dye sensitized solar cell* (DSSC) berbasis TiO2 *single layer* dan *double layer.* [Comparative analysis of the efficiency value of the production of dye-sensitized solar cell (DSSC) prototypes based on single-layer and double-layer TiO2]. *Proceedings of Seminar Fisika dan Aplikasinya* (pp. 203–208). Surabaya, Indonesia: ITS.

Solar energy, the industry for the future of energy [*Tenaga surya, industri masa depan energi*]. (2010, November 14). *Republika*. Retrieved on 28 April 2015 from http://www.republika.co.id/berita/koran/industri/14/11/10/neta4a27-tenaga-surya-industri-masa-depan-energi.

Solar photovoltaic: As one of the energy solutions for Indonesia.[Handout of Presentation]. Jakarta, Indonesia: PT Wijaya Karya.

Solar Surya Indonesia (2015). *Kini rumah bisa jual listrik ke PLN* [Houses can now sell electricity to PLN]. Retrieved from http://solarsuryaindonesia.com/news/kini-rumah-bisa-jual-listrik-ke-pln.

Sopandi, A. (2012). *LEN Industri siap produksi sel surya* [LEN Industry is ready to produce solar cells]. Retrieved on 12 July 2015 from http://industri.bisnis.com/read/20120426/257/74386/len-industri-siap-produksi-sel-surya.

Sumiarso, L. (2010). *Pengembangan panel surya di Indonesia sudah dimulai sejak 1970.* [Solar panel development in Indonesia has begun since 1970]. Retrieved on 30 March 2015 from http://esdm.go.id/news-archives/323-energi-baru-dan-terbarukan/3941-pengembangan-panel-surya-di-indonesia-sudah-dimulai-sejak-1970.html.

Sumiarso, L. (2011). *Kebijakan energy baru, energy terbarukan, dan konservasi energi.* [Policies on new energy, renewable energy and energy conservation]. Retrieved on 30 March 2015 from http://webcache.googleusercontent.com/search?q=cache:LAqz1ybk_ewJ:www.lppm.itb.ac.id/wp-content/uploads/2011/01/Paparan_Dirjen_EBTKE.pptx+&cd=1&hl=en&ct=clnk&gl=id .

Suurs, R. A., & Hekkert, M. P. (2009a). Cumulative causation in the formation of a technological innovation system: The case of bio-fuels in the Netherlands. *Technological Forecasting and Social Change*, *76*(8), 1003–1020. (https://doi.org/10.1016/j.enpol.2009.09.032).

Suurs, R. A., & Hekkert, M. P. (2009b). Competition between first and second generation technologies: Lessons from the formation of a bio-fuels innovation system in the Netherlands. *Energy*, *34*(5), 669–679.

Suurs, R. A., Hekkert, M. P., & Smits, R. E. (2009). Understanding the build-up of a technological innovation system around hydrogen and fuel cell technologies. *International Journal of Hydrogen Energy*, *34*(24), 9639–9654.

Suurs, R. A., Hekkert, M. P., Kieboom, S., & Smits, R. E. (2010). Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel. *Energy Policy*, *38*(1), 419–431.

Vasseur, V., Kamp, L. M., & Negro, S. O. (2013). A comparative analysis of Photovoltaic Technological Innovation Systems including international dimensions: The cases of Japan and the Netherlands. *Journal of Cleaner Production*, *48*, 200–210.

Widodo, D. A., Suryono, Tatyantoro, A., & Tugino. (2009). *Pemberdayaan energi matahari sebagai energi listrik lampu pengatur lalu lintas* [The empowerment of solar energy as electricity for traffic lights]. [Unpublished paper], Semarang, Indonesia: Faculty of Economy and Faculty of Technic, Semarang State University.

Witjaksana, Y. (2005, January). Pemanfaatan sel surya secara nasional, [The utilization of solar cells nationally]. Paper presented at the *Workshop for Renewable Energy Technology Reviewed from Gender Perspective in Indonesia*, Yogyakarta, Indonesia.

Yin, R. K. (2003). *Case study research: Design and methods.* London: SAGE Publications.

Notes:

1. In the 1980s, LEN was a subsidiary of LIPI which conducted research activities. In 1991, PT LEN became a separate institution. PT LEN is now a state-owned enterprise in the electronics and telecommunications sector.
2. Before the Reform era, the total number of provinces in Indonesia was 27. In 2017, there are 34.
3. The project installed in Kentang Village, Gunung Kidul, Yogyakarta had a capacity of 19 kWp (battery capacity of 200 volts) for 85 houses, and was managed by a village cooperative unit (KUD) (Almanda, 1997).
4. Normally, Indonesia elects a president once every five years.
5. In 2002, few NRE programs were dealt by Directorate of NREs and Energy Conservation. This unit was part of General Directorate of the Use of Electricity and Energy at the Ministry of Energy and Mineral Resources.
6. KEN 2003–2020 explicitly mentions the creation of NREs, i.e geothermal, biomass, and micro/mini hydropower, and grow them to as much as 5% of total energy by 2020. PV targets in particular do not pertain to this regulation.
7. In 1997–1998, the World Bank also provided commercial loans for SHS development amounting to US$20 million, but it was cancelled owing to the 1997 financial crisis (Witjaksana, 2005).
8. In 2010, all departments in Indonesia were changed to ministries, e.g. the Department of Energy and Mineral Resources was changed into to the Ministry of Energy and Mineral Resources (Presidential Decree No. 47/2009 on Formation and State Ministry Organization).

9. Before Dirjen EBTKE was formed, development of NREs was headed by the Directorate of NREs and Energy Conservation at the Ministry of Energy and Mineral Resources.
10. APAMSI's members are the six domestic PV manufacturers: PT LEN Industri (Persero); PT Adyawinsa Electrical & Power; PT Surya Utama Putra; PT Swadaya Prima Utama; PT Azet Surya Lestari; and PT Wijaya Karya Intra de Energi.
11. The Government of Indonesia issued Government Regulation No. 4/2010 on the Appointment of PLN in Implementing the Acceleration of Development of Energy Generators Using New and Renewable Energy, Coal, and Gas.
12. Research reveals that 30 metric tons of quartz sand will yield 8 metric ton of sillicon. By using recent technology, this yields 1 MW of solar cells (Oemry, 2012).
13. According to the plan, it would be located in Karawang, West Java (with a capacity of 60 MW for crystal silicon and 30 MW for solar modules). 50% of PV products was to be used by PT LEN, and the rest would be sold to other PV manufactures in Indonesia (Akhmad, 2012). The fund was predicted to be around US$ 45.4 million for wafer and US$ 5 million for solar modules. It was predicted to be completed by 2013 (Oemry, 2012). Unfortunately, this project failed to be actually implemented until very recently in 2017.
14. PLN's PLTS infrastructure, for examples in Buku Limau Island, Bangka Belitung; Three Gili Island, West Nusa Tenggara, etc.
15. The Indonesian National Standard (SNI) for PV is s follows: a) SNI IEC No. 61215:2013 - Photovoltaic module, silicon crystal, qualification design; b) SNI IEC No. 61194:2013 – Parameter of independently photovoltaic system characteristic.
16. If subsidies for electricity and oil are combined, they reach up to Rp 299.8 trillion (US$ 27 billion) or 2.5% of gross domestic products, and 25% of the national budget (International Institute for Sustainable Development, 2014). Other sources claim that the government had allocated Rp 78.63 trillion to subsidize electricity (ESDMmag 7, 2012).
17. Electricity received by PLN from the solar panel will be offset by PLN with electricity energy which is sent to PLN's customers. If electricity received by PLN from the PV is more than the electricity sent by PLN, its electricity margin becomes an electricity deposit which will be accounted in electricity use in the next months. Based on Regulation of the Minister of Energy and Mineral Resources No. 4/2014. More information can be found at http://microsite.metrotvnews.com/indonesiamemilih/read/2013/11/21/7/196175/PLN-Barter-Listrik-Pelanggan-Pengguna-Panel-Surya.
18. Intervention from Habibie as the Minister of Research and Technology (Menristek), Chief of the BPPT, and Chief of the National Research Council in 1978–1997 was dominant in influencing government policy in the New Order regime. In this period, PV development initiated by the BPPT was strongly supported by the central government.