Sectoral systems of innovation: A case study of solar photovoltaics

Kohzo Ito, Professor, The University of Tokyo
Masaru Yarime, Associate Professor, City University of Hong Kong
Ranaporn Tantiwechwuttikul, PhD Candidate, The University of Tokyo (corresponding author)

ranaporn@s.k.u-tokyo.ac.jp
Freiheit 103, Wakaishiba 276-1,
Kashiwa city, Chiba 277-0871
JAPAN

1. Introduction

Despite the dissimilar forms of energy abiding in each renewable resource, all can be converted into electricity, which is the most convenient energy vector. As electricity is easily transformed (into other forms such as light and heat), conveniently transmitted and stored, and widely considered as a fundamental enabler of modern society. Notwithstanding the beneficiary, all renewables accounted for about 20% of the estimated global final energy consumption in 2015 and less than 2% was from the modern technologies namely wind turbine or solar photovoltaics (REN21 2016). Hence, the mechanism to promote renewable technology adoption is ultimately crucial to secure sustainable energy futures.

Amongst alternatives, solar energy provides great potentials thanks to its abundance and predictability. And a single-step conversion from sunlight to electricity by means of *solar photovoltaics (PV)* has gained the highest market growth rate accelerated by rapid technological learning rate and thus cost reduction. Yet, in comparison to conventional power generation systems, PV market adoption is still very reticent and concentrated particularly on the silicon-based PV. The barriers of PV deployment typically revolve around the issues of technological challenges and non-technological aspects i.e. public policy and economics. Though the in-depth – yet disintegrated – analysis was conducted by experts in the respective fields to highlight some issues, the lack of all-encompassing perspective is where this research aimed to fulfil.

A methodological framework of sectoral systems of innovation is incorporated to identify three elements (namely knowledge and technology, actors and networks, and institutions) and to gain a better understanding of PV industry structure, dynamics, and transformation. Case study approach is applied for two distinct concepts: (1) **Macroscopic level** analysis of PV market in five theoretical sampling countries (Germany, China, Malaysia, Thailand, and India); and (2) **Microscopic level** analysis in Thailand due to a unique case feature of over-dominant utility-scaled PV installation pattern. As examined in Thailand, technological exploitation has utterly been given priority, and probably at the expense of technological exploration. Hence, approaches to secure both technological diffusion and innovation are synthesised. One conclusion is grounded on innovation catching-up strategies emphasising crucial role of institutional instruments, especially for the latecomer countries, as well as the balancing in policy between technological exploitation and exploration.

2. Methodological framework

Provide a more comprehensive approach to the analysis of sectoral differences in innovation and innovation activities, sectoral systems framework is a multi-dimensional, integrated, and dynamic approach aiming to better understand the driving forces for innovative activities and how these forces change over time. Framework of sectoral systems is grounded on three areas of research in economics and innovation studies. Firstly, the *industrial transformation* addresses on dynamic process of innovative activities patterns and change in technological regimes. Secondly, the *evolutionary theory* emphasises on economic transformation where learning and knowledge play crucial roles, also its dynamics and innovation processes. And thirdly, the *innovation systems* signify the interactive process involving firms and non-firm organisations (Malerba 2002).

Serving as a methodology for analysing the sectors' characteristics and for comparing the innovation drivers across different sector, sectoral systems of innovation define a sector as a set of activities associated with broad and related product groups which address similar existing or emerging demands and share common knowledge bases. Three main elements, each has its own characteristics and set of dynamics, are (Malerba and Adams 2013):

- *Knowledge and technological domains*: Specific knowledge base and technologies set different sectors apart and play a central role for this framework. The analysis seeks to understand how knowledge and technologies are created, how they flow and are exchange, and how such transaction may redefine sectoral boundaries.
- *Actors and networks*: Uniqueness and capability embedded within heterogeneous agents demonstrate their specific learning processes, competencies, and behaviours. In addition, their interactions and networks foster the generation and exchange of knowledge.
- *Institutions*: No necessary bounded within national dimension or formal organisation, institutions provide conditions – by created or imposed on – actors and networks.

This framework offers unique practicality in terms of covering wide range of factors, considering major driver from firms and learning process, and providing dynamic perspective as well as a process view. This broad, flexible, and adaptable tool allows different levels of aggregation which depend on the purpose of analysis. With regards to this aspect, this research adopts the sectoral systems of innovation as methodological framework for both macroscopic and microscopic level analysis.

3. Macroscopic level analysis

Rationale for countries' selection are based on key characteristics of PV industry within each nation: **Germany** is world's leader continuity of PV policy and installation; **China** is low-cost leadership of PV production and has exceeded Germany in terms of cumulative installed capacity since 2015; **Malaysia** becomes one global PV manufacturing location thanks to its existing semiconductor research, but depicts marginal domestic installation; **Thailand** shows uncommon PV installation pattern over-dominated by utility-scale projects (>1MW PV system); and **India** demonstrates the most rapid PV market growth doubling its installed capacity during 2015-2016, in addition to novel PV initiatives and alternative financing options, especially for solar lighting systems and solar home systems. PV industry characterists and key policies of five countries are summariesed in Table 1.

Table 1 Comparative PV policy development in five countries

	Germany	China	Malaysia	Thailand	India
Significances	▪ World's leader PV installation ▪ Well-known for continuity of PV policy	▪ Low-cost leadership of PV production ▪ World largest PV cumulative installation capacity since 2015 ▪ Silicon R&D technology	▪ Technology-advanced PV production ▪ Benefit from well-established semiconductor industry	▪ Early PV technological adoption in ASEAN ▪ Uncommon PV installation pattern	▪ Rapid PV uptakes since 2010 ▪ Benefit from distributed PV systems ▪ Innovative financial mechanism
Key PV policies (year)	'90 Financial incentive for early adoption '00 Build PV industry '04 Limit rising costs of society '11 Grid integration; deman-side managemen t	'80 Rural electrification '03 Export-oriented industrial strategy '09 Domestic deployment '12 Infrastructure development	'90 Rural electrification '06 Grid-connected PV on buildings (BIPV) '10 National R&D strategy; domestic capacity development	'85 Rural electrification '07 Renewable energy (RE) financial incentives '10 Solar adder terminated '13 Rooftop FiT '16 Regional solar hub roadmap	'98 Electric sector liberalisation '10 Jawaharlal Nehru National Solar Mission (JNNSM) PV policy for 22GWp target by 2022 '15 New PV target more than 100GWp
Shifting in policy	▪ Tariff regression ▪ Grid integration ▪ Self-consumption	▪ Grid-connected PV systems	▪ Niche R&D	▪ Residential rooftop PV ▪ Self-consumption	▪ National-wide PV projects
Issues relted to PV	▪ Grid stabilisation	▪ Trade dispute ▪ PV module quality control	▪ Marginal domestic PV installation	▪ Policy inconsistency ▪ Over-dominant utility-scale PV system	▪ Losses in transmission & distribution lines ▪ PV under-utilisation due to dust issue

German feed-in tariff (FiT) programme, indeed, triggered an unprecedented phase of market expansion, and enabled mobilisation of private investment for PV production and installation far beyonds its national boundary. Initially, German gain competitive advantages as the first technological mover, which then supported the build-up of domestic PV industry during 1990s-2003. Subsequently, China adopted PV technological diffusion particularly in PV manufacturing. These transnational linkages could not solely be explained by the *lead-lag market model* - a linear concept of the internationalisation of demand driving the internationalisation of supply. Instead, many studies on PV technological innovation systems between these two contries have revealed empirical data of co-evoluted and reinforced patterns through indirect spillovers and feedbacks mechanism of knowledge and technology domain (Grau, Huo, and Neuhoff 2012; Zhi et al. 2014; Quitzow 2015). Demonstration effect is another key driver in two regards: PV deployment (from Germany to global market) and PV production (from low-cost production in China to niche R&D in Malaysia). While the product innovation tends to be originated from Western countries where R&D activities are strongly asserted, the process innovation is impresively generated from the developing countries along the manufacturing process, installation and operation. Germany still holds strong position in inverters and PV-related equipments, where profit share is relatively high. Pursuiting cost-competitive advantages, China (including Taiwan) places strong R&D activities in upstream supply chain which consequently results in the drastic decline of PV module cost globally during 2004-2008.

Albeit other factors, Chinese trade dispute with major importer countries and the global financial crisis during 2007-2009 shinked global PV demand. Counter-mechanisms from both internation firms and government decisions lead to two phenomena: the expansion of PV manufacturing firms outside China, and the Chinese PV domestic market adoption. From this viewpoint, the role of institutions is truly critical not only the rate of technological change, but also the organisation of innovation activity and performance. The deliberate and well-planned decisions especially in Germany, China and Malaysia affirms the active national policies' influences. Despite a marginal domestic PV installation, Malaysia adopts FiT based on the polluter payers schemes and Renewable Portfolio Standards (RPS) to facilitate renewable energy (RE) growth, along side with strategic R&D aiming to moving up PV value chain. Nevertheless, the unpredicted consequence of actors' interaction demands the improvising strategies and quick policy responses from national institutions. Cases of Thailand and India clearly addressed this issue.

Three categories of policy design help calrify different aspects concerning PV diffusion in government agenda (IET 2015):

1) Market-based support mechanism can be classified into two sub-categories.

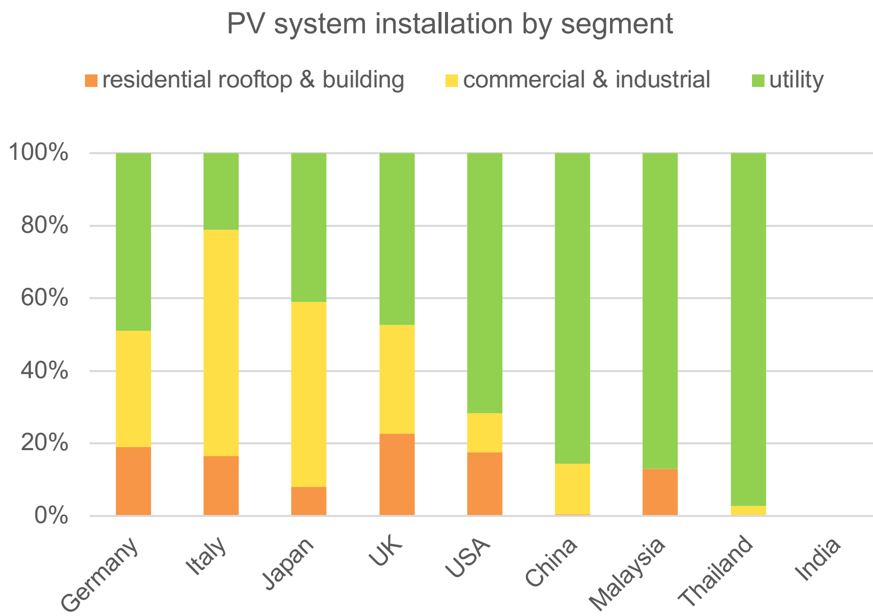
- 1.1 Price-based market instruments – price is determined by the policymaker, whereas quantity regulated by the market. In addition to price, the policy can be investment-focused (i.g. investment subsidies, tax incentives) and generation-focused (i.e. FiT, net metering).
- 1.2 Quantity-based market instruments – quantity is determined by the policymaker, whereas price is determined by the market. Quota obligation (tradable green certificates/renewable portfolio standards), tender scheme, and auctions are amongst policy choices.

2) Regulatory policy: grid connection capacity, adminstrative procedures, and technical standards are amongst policy options aiming for RE project estabishment and streamline project execution.
3) Flanking policy includes, but not limited to, R&D grants/fundings, education & training programmes, and soft loans.

Despite different degree of PV policy deployment, clearly all five countries adopt and promote market-based support mechanisms. However, regulatory and flanking policies are substantially important and need more attention particularly in developing countries. Considering actors and networks in PV industry, apart from typical firms and non-firm organisations directly involved with PV market (e.g. utilities, equipment suppliers, academia, and financing entities), the regional and national PV targets promote the goal-driven strategies and accelerate the implementation as witnessed across EU and ASEAN countries. Furthermore, international and regional collaboration foster knowledge transfer through investment (e.g. Asia Development Bank funded PV projects, UN Green Climate Fund) and educational programmes (e.g. RENAC – Renewables Academy based in Germany providing training courses via online, summer schools, and outreach projects particulary for developing countries; PV technology focus is applied to India, Philippines, and Thailand).

Based on case study approch, five countries are selected based on theoretical sampling aiming to draw attentions to specific issues. Besides the cross-country inter-dependencies and influences of PV global market and dynamics, the environmental variation embeded within each national setting also provide or highlighten uncommon occurance. The analysis of PV installation pattern based on how PV systems have been installed as rooftop, building, or ground-mounted systems can, to some extent, reflect segmentation of PV market broadly classified as residential, commercial/industrial, and utility-scale projects. Based on the most recent available database and each country's classification, Figure 1 displays PV system installation pattern (grid-connected) in five selected countries along with other top four countries. Applied country-income criteria (REN21 2016), three groupings are the high-income countries (Germany, Italy, Japan, UK, and US), the upper-middle income countries (China, Malaysia, and Thailand), and the lower-middle income country (India). Unfortunately, no data of PV system size installation in India is available; given that India is selected as a case study based on its lack of grid infrastructure, thus a lack of detailed grid-connected database has been anticipated in advance. Details is provided in Appendix A.

Segmentation addresses not only the direct impacts from PV policy on technological diffusion, but also other technical challenges. PV ground-mounted system typically infer as utility-scale project which intrinsically require large area of land use and availability of grid-connected capacity. Some ground-mounted system may incorporate tracking devices to enhance energy yield. Ground-mounted system can also be deployed as micro-grid management or community electricifcation. PV rooftop and building integrated PV (BIPV), on the other hand, can utilise the existing available space, but may trade off with energy yield depending on the orientation and inclination (tilt) of PV modules installed on the fixed roof or façade. Both rooftop and BIPV can be deployed as grid-tied (sell elelctricity to the grid) or self-consumption. Despite variation of the absolute number of cumulative installed capacity in each country, the governments in developed countries put strong emphasis on rooftop and BIPV systems in their policy design, whereas the developing countries' PV policy tend to in favour of utility-scale projects – which easier to manage and integrate into an existing centralised electricity grid system.



Note: Own compilation and classification

Figure 1 PV system installation by segment in selected countries

Policy shifting is amongst outstanding themes in which governments largely shift from *governance by rules* to *governance by goals*, and the private sector plays an increasingly important role in the PV market. In terms of market intervention policy, Germany gears towards tariff regression and eventually phase-out, and the promotion of innovative financial mechanisms is advocated worldwide. In terms of PV system installation, the trend shifts from centralised grid-connected systems to distributed systems (e.g. rooftop, self-consumption, off-grid/standalone). Despite the geopolitical uniqueness, the trend towards distributed system and innovative investment mechanism will certainly catalyse technological diffusion. Yet, the challenges remain not only to compete with well-established conventional technologies (particularly coal-fired power plant in developing countries), but also how to implement PV different technologies in unique settings in order to optimise its potential.

4. Microscopic level analysis

The comparative review subsequently reiterates a unique case feature (over-dominant utility-scaled PV installation pattern) in Thailand, hence a microscopic level analysis of a richly observed single case is conducted to capture the nature of institutional setting which has profound impacts through policy planning and interventions. Thailand's first renewable energy development plan in 2007 was designed to secure upfront investment in the solar industry, which consequently led to the dominance of utility-scale projects (more than 97% of 2309.842MW PV operating capacity in 2016). From national and international perspectives, however, more diversified and decentralized projects should be prioritised, and incorporate more public awareness and engagement. Thus, the Thai Feed-in Tariff programme in 2013 helped encourage technological adoption in the residential sector; yet the financial burden incurred by the Thai society was amongst leading issues which limited PV installation potential. A recent pilot programme using solar rooftops for self-consumption was launched in 2016, and set a new platform for the near-future PV policy direction to stimulate rooftop PV growth as part an ambitious goal of solar power generating 6000MW by 2036 (MoE 2017).

PV value chain can generally be divided into two levels: Upstream (including manufacturing of PV module and the balance of system), and Downstream (including project planning phase, implementation phase, and use phase). At present, Thailand's PV industry is focused on downstream deployment. Thus, analysis based on sectoral system of innovation (SSI) framework emphasises the downstream activities covering three phases from PV project planning and development, to PV system installation including EPC, and to project realisation including ownership transfer and O&M.

In 2015, PV shares about 17.83% of total RE generating capacity in Thailand, and approximately 1.36% of total electricity demand (IEA PVPS and DEDE 2016). Hence, there is huge space for further PV market growth. An early PV technological adoption from 2008 took advantages from both the global PV price declination and government price-based market instrument. Adder programme can be claimed as a successful mechanism which has ignited domestic PV market and induced PV technological adoption to the fossile fuel-based power sector. An additional 200MW rooftop PV under FiT in 2013 helps stimulate market growth in residential and commercial sectors. However, the capped quota does limit market growth, while financial burden on society via pass-through policy expense in power tariff structure is subjected for further analysis due to higher impact from fuel cost (by natural gas price volatility). The unspecified location policy leads to PV project clusters located far from electricity demands. Greater transmission and distribution losses, and grid stability are amongst major issues to be anticipated at the higher PV penetration level. Nonetheless, the dispropotional investment is reflected by PV project segmentation – the over-dominance of utility-scale system. Strikingly, more than 62% of total PV operating capacity in 2016 are owned by merely 12 key market players. Four types of PV project owners are proposed to capture companies' core competencies and how knowledge creation/sharing is florish through co-investment projects. Further analysis on sectoral systems determines at least four challenges facing PV sector in Thailand which are:

(1) PV project uncertainty after policy termination. PPA contract of PV projects under Adder programme is 10 years. If the cost of electricity from PV project is not competitive to the conventional power plants by that time, PV project owners may discontinue PV projects by the end of its contract. Thus, market conditions will play greater role.

(2) Technical issues of grid integration, espectirally at the higher PV penetration level. Impacts from grid-tied PV system inherit different issues. Though a prosumer, concept of self-generation and self-consumption, will strengthen a notion of energy security particularly on a household level, a broader perspective of national grid system security may not be positive. So far, no study has been done to forecast a threshold of PV penetration level which will have adverse effect on grid system due to either grid-connected or grid-tied PV systems.

(3) Financial issues of the fixed cost of grid system. From the utility viewpoint, a distributed PV system employed for self-consumption purpose can be perceived as two primary business threats. First threat, explicitly, is the lower electricity demand; the reduce in electricity sales (assuming a business-as-usual of constant electricity

demand). Second threat is about the fixed cost of standby grid system; in other words, the fixed cost of service shares amongst ratepayers, and PV adopters tend to be the free riders. Therefore, the interdependence of revenue and rate impacts of the future government supporting PV monetary scheme (e.g. net metering, net billing) requires delicate analysis to minimise possible negative effects on retail electricity prices.

(4) PV propect and industrial growth outlook. PV industry in Thailand has been very active since 2008 and will surely continue to grow; but towards what directions? A roadmap of Thailand's solar power development to 2035 proposed three scenarios: (1) domestic market boom, (2) ASEAN market leader, and (3) open and innovative market (Tongsopit et al. 2015). All scenarios are plausible given specific drivers namely proactive consumers, institutional arrangements, and strategic repositioning of Thai policy and industrial competitiveness. Furthermore, the sectoral analysis emphasises on the dynamics and co-evolution of all three elements: Knowledge and technological domains, Actors and networks, and Institutional factors. The co-exist and further market growth of both rooftop PV in residential and commercial sector, and ground-mounted utility-scale PV system are attainable, but do require different sets of policy instruments and supporting systems.

5. Implication for sustainability

5.1 Conditions for catch-up

Institutional instruments are crucial to provide a prerequisite for PV technological exploitation and exploration. The core of policy design should envision a balance perspective, but whether the execution is simultaneous or sequential is subject to national settings, market conditions, and capability. Either exploitation or exploration, conditions for catch-up will be more stringent over time from not only the current and near-future global and domestic market factors, but also other technology discontinuities and disruptions. Thus, policy should be designed systemically, rather than compartmentally.

PV technological exploitation is unique because a rapid cost reduction greatly rewards the late technological adopters. On the flip side, PV projects can be intentionally delay taking this cost advantage. Since the cost reduction embedded in PV model is marginal comparing to cost reduction in the balance of system, the benefits from PV project realisation should surplus PV cost saving. In addition, greater demands on technological capability is in line to other radical technological changes and improvement (e.g. ICT, weather forecasts, energy storage technologies) which help optimise and/or enhance PV system. Therefore, technological exploitation should be considered from a collective manner of PV industry and related technologies, and the benefits include both direct and indirect.

PV technological exploration can take advantage from the triple helix of university-industry-government interactions. To pursuit knowledge-based societies, many routes are possible namely: the statist model where government is the dominant institutional sphere; the laissez-faire model where each institutional sphere is clearly separated; the field interaction model of helices with an internal core and external field space of each entity. University technology transfer capabilities can be made from research group, liaison office, technology transfer office and incubator (Etzkowitz 2008).

5.2 PV grid parity and a shift towards self-consumption

Grid parity refers to a point in time when the levelised cost of electricity (LCOE) of an alternative energy source is less than or equal to the cost of retail electricity in a given country. In a context of PV, reaching grid parity determines PV technological competitiveness without subsidies or government support. Thanks to the economies of scale, utility PV is normally the first system to reach grid parity, and self-consumption PV system ranks the last. Regardless of PV system, the same three stages apply: uncompetitive PV, partial competitive, and competitive. The valuation of PV power output in each stage determines the monetary value of supporting schemes.

As PV system deployment has been shifted from utility-scale PV power plant to distributed PV (DPV) system, these dynamics reflect a profound energy transition from supply-side to demand-side where consumer becomes prosumer who is capable of self-generation and self-consumption of electricity. Besides the common benefits associated with other RE technologies e.g. reduced/avoided CO_2 emission, green growth and job creation), certain benefits of DPV are as follows:

- Avoided electricity generating costs and peak demand shaving: PV output yields maximum capacity during daytime which matches with highest electricity demand in many countries (Thailand is included). Hence, DPV can substitute or reduce the usage of expansive standby power plants.
- Avoided transmission and distribution (T&D) costs and losses: DPV is installed on-site, and its output is used locally. Thereby centralised T&D network is not required.
- Avoided investment in new power plant capacity in centralised power system: despite intermittency issues, DPV can serve the additional power demand which tends to increase with economic growth, especially in the developing countries.
- Supporting grid stability as ancillary services: DPV can provide reactive power which then support the medium and high voltage grid in times of voltage dips (voltage ride-through capability) (RENAC 2016).

However, DPV can have negative impacts on some stakeholders and some debatable issues:

- Utility opportunity and revenue lost: when consumers process self-generating capability, demand from grid become secondary.
- System integration costs particularly a fixed cost of standby grid system that PV adopters tend to be the free riders; one possible counter-measure is to levy grid (accessibility and/or usage) fees.
- Decreased tax revenues: tax authorities may face decreasing tax revenues due to the decreasing retail sales of electricity grid.

During an initial uncompetitive PV stage, government tends to use subsidies or levies as policy incentives (i.e. feed-in premium, FiT) to encourage technological uptakes. In partial competitiveness stage, the value of DPV output is about the same as retail price; net-metering scheme is usually exercised. Net-metering allows customer to run the meter backwards by exporting power back to the grid, or in other words the grid functions as power bank). However, one argument from policy marker's is that the value of DPV should not equal to retail price, otherwise consumer will aim to sell electricity to the grid (given that selling option is available). Thus, different policy tools are designed to allow the adjustable value of the excess output from DPV; one policy choice is net-billing. But policy implementation may face challenges particularly in retail sales market.

6. Concluding remarks

Electricity is one fundamental enabler of modern society and we are, indeed, in a midst of the profound shift in energy transition. In coherence with the Sustainable Development Goals (SDGs), this research addresses particularly on *Goal 7 - the affordable and clean energy*. The dispersed nature of renewable energy resources and viable technologies can potentially secure energy demands. Reduction in fossil fuels consumption and the promotion of renewable energy will be a critical pathway towards a low carbon society. Amongst different renewable energy resources, solar photovoltaics (PV) is carefully selected as a subject of research, because the market adoption is still very limited and concentrated particularly on the earliest PV technology since the 1960s despite a series of technological breakthroughs. This research aims to provide the holistic approaches and mechanisms to firstly secure PV technological diffusion, then to establish technological advancement capacity based on local competency and applicability. So that the latecomer countries can be benefit from technological leapfrogging, as much as contribute or share certain knowledge to the global context.

A methodological framework of sectoral systems of innovation reveals structure and interactions embedded in PV sector. Three elements of knowledge and technological domains, actors and networks, and institutions are identified and examined each elements' characteristics and set of dynamics. Indeed, policy-induced technological change plays crucial role in PV industry through national strategic development plan, institutional establishment and arrangement, and firm product and process innovations. But the knowledge and technological domains are often lack behind, particularly in developing countries. Therefore, the PV policy needs a systematically, not a compartmentally, perspective and the balance of policy in technological exploitation and exploration with a timely policy adaptation. Furthermore, the systems approach analysis extends a discussion on PV industry development from focusing merely PV supply chain to involving collectively PV-related industries. Each nation does require to create the political and economic conditions for establishing a robust, multi-faceted policy to anticipate and accommodate such technological transition: not only for the purpose of short-term technological catch-up, but also for the long-term technological competitiveness through a vision of the knowledge-based society.

This research endeavour to ascertain the socio-technical mechanisms underlying PV innovation dynamics, and how this understanding can lead to a more sustainable energy supply and sidestep technological lock-in. Further PV technological exploitation and exploration are politically practical and commercially feasible. And neither science and technology nor policy and society is solely sufficient; the co-evolution, integration, and alignment of all compositions are essential for the sustainable energy futures.

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Appendix A

Table A-1 Classification of PV segmentation

	Classification based on data sources						Classification used in this thesis			Data sources	Database
	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Tier 6	Group 1	Group 2	Group 3		
HIGH-INCOME COUNTRIES											
Germany	<10kW	10- <100 kW	100-500 kW	>500kW			Tier 1	Tier 2 Tier 3	Tier 4	Fraunhofer ISE	End-2016
Italy	<3kW	3- <20kW	20- <200kW	200kW-1MW	>1MW		Tier 1 Tier 2	Tier 3 Tier 4	Tier 5		End-April 2017
Japan*	<10kW	10- <50kW	50- <500kW	500kW- <1MW	1- <2MW	≥2MW	Tier 1	Tier 2 Tier 3 Tier 4	Tier 5 Tier 6	New Energy & Industrial Technology Devel. Organization (NEDO)	Added in 2015
UK	≤4kW	4- ≤10kW	10- ≤50kW	50kW- ≤5MW	5- ≤25MW	>25MW	Tier 1 Tier 2	Tier 3 Tier 4	Tier 5 Tier 6	Dept for Business, Energy & Industrial Strategy	End-2016
USA*	Residential	Non-residential	Utility				Tier 1	Tier 2	Tier 3	Solar Energy Industries Association (SEIA)	Added in 2016
UPPER-MIDDLE COUNTRIES											
China	PV products	Building	Commercial & Industrial	Ground-mounted			Tier 1 Tier 2	Tier 3	Tier 4	CPVE, IEA-PVPS	End-2015
Malaysia	Individual	Non-individual	Community				Tier 1		Tier 2 Tier 3	Sustainable Energy Devel. Authority Malaysia (SEDA)	End-Jan 2014
Thailand	≤10kW	>10-250kW	>250kW-1MW	>1-10MW	>10-90MW		Tier 1	Tier 2 Tier 3	Tier 4 Tier 5	Energy Regulatory Commission (ERC)	End-2016
LOWER-MIDDLE INCOME COUNTRY											
India	n/a									Central Electricity Authority, Ministry of Power	

Data sources: (Fraunhofer ISE 2017; GSE 2017; IEA PVPS and NEDO 2016; UK National Statistics 2017; SEIA 2017; IEA PVPS and CPVS 2016; IEA PVPS and SEDA 2016; ERC 2017; CEA 2017)

Table A-2 Database of PV segmentation

	Amount of PV system installation (MW)						Share of PV segmentation (%)			Data sources	Database
	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Tier 6	Group 1	Group 2	Group 3		
HIGH-INCOME COUNTRIES											
Germany	7524	4752	7920	19404			19.0%	32.0%	49.0%	Fraunhofer ISE	End-2016
Italy	490	2424	3811	7273	3750		16.4%	62.5%	21.1%		End-April 2017
Japan*	863	3581	893	1020	2784	1625	8.0%	51.0%	41.0%	New Energy & Industrial Technology Devel. Organization (NEDO)	Added in 2015
UK	2459	199	722	2792	4163	1399	22.7%	29.9%	47.4%	Dept for Business, Energy & Industrial Strategy	End-2016
USA*	2583	1586	10593				17.5%	10.7%	71.8%	Solar Energy Industries Association (SEIA)	Added in 2016
UPPER-MIDDLE COUNTRIES											
China	85	6060	85	37120			14.2%	0.2%	85.6%	CPVE, IEA-PVPS	End-2015
Malaysia	14.091	12.026	0.709				52.5%	0.0%	47.5%	Sustainable Energy Devel. Authority Malaysia (SEDA)	End-Jan 2014
Thailand	0.181	0.896	61.335	1811.430	436.000		0.0%	2.7%	97.3%	Energy Regulatory Commission (ERC)	End-2016
LOWER-MIDDLE INCOME COUNTRY											
India	n/a									Central Electricity Authority, Ministry of Power	

Data sources: (Fraunhofer ISE, 2017; GSE, 2017; IEA PVPS & NEDO, 2016; UK National Statistics, 2017; SEIA, 2017; IEA PVPS & CPVS, 2016; IEA PVPS & SEDA, 2016; ERC, 2017; CEA, 2017)