Assessment of Feed in Tariff Policy Impacts for Promoting Wind and Solar Energy Development in Japan

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by

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Introduction

Overview

This chapter provides a background on the research topic under study. It explains the research design; the questions answered during the study and the methodology used to respond to these issues. Finally, it briefly introduces the outline of this study with a short summary of each chapter.

Research background

The development of alternative energy sources in Japan was primarily motivated by the desire for energy security and stability of supply. The oil shock in the 1970s and Fukushima accident in 2011 were the most important events shaping current energy policy in Japan and set its direction. After the oil shock, nuclear energy was considered a strategic option with an important role to play in the energy mix. Despite the anti-nuclear movements around the world, the share of nuclear energy in the Japanese energy mix continued to increase until 2011. Environmentalists have considered this an obstacle to the development of renewables.

Nevertheless, there have been significant budgets allocated for the research and development (R&D), and the promotion of renewable energy, in Japan. Following the United States renewable energy policy, the Renewable Portfolio Standard (RPS) was adopted in Japan in 2003. However, it was deemed ineffective. The feed-in-tariff (FIT) policy was successful in European countries led by Germany, Spain, and Italy, and a partial form of it was introduced in Japan in 2009. The German FIT program was initially used as a role model, and later an extended form of FIT was added in 2012. The following policy achieved a significant increase in the share of renewable energy, for solar photovoltaic (PV) in particular.

One of the primary reasons for the success of the FIT is the guaranteed provision of long-term, fixed revenue that reduces the risk of investors. The financial guarantees provided by the feed in tariff policy made the investment in renewable energy more attractive than for conventional subsidy programs, like the sunshine project in Japan. Moreover, the FIT policy created a significant market demand, which offered a viable opportunity for commercialization of the technological research and innovation that have accumulated over the last three decades.

The FIT policy, however, comes with a significant cost that is passed on to electricity end users, and which raises concerns about its justification. The electricity prices in Japan have increased by 37% between 2011, when FIT surcharges were first introduced, and July 2014 (METI, 2014c).

Policy costs, in general, are justified based on policy objectives and the socio-economic benefits the policy is designed to achieve. Most of the relevant policy research have been focused on the financial and technological objectives of renewable energy promotion policies. In such analyses, the social benefits are not considered in the evaluation assessment; therefore, renewable energy cannot be fully justified against lower-cost alternatives using fossil-fuel energy sources. Therefore, critics of renewable energy development argue that renewable energy is not a cost-effective strategy. Other scholars like (Edenhofer, Hirth, et al., 2013) stressed that renewable energy promotion policies (like the FIT) should be justified by multiple objectives and that all benefits should be explored to reach a fair evaluation. For example, in Japan, neither green employment nor promotion of local industry is listed among the objectives of the FIT policy. Moreover, carbon emission and the energy transition strategy are not tightly linked with the feed in tariff policy. The exclusion of these interactions conceals the full benefit of renewables.

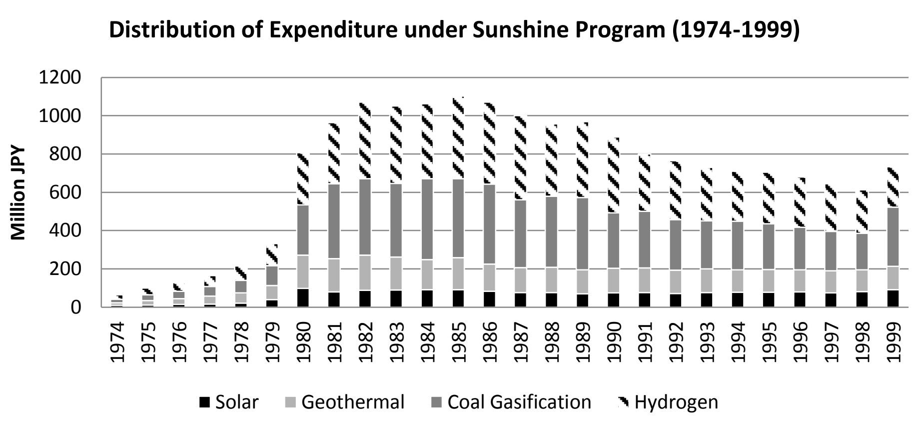


Figure 0-1: Expenditure on renewable energy development in Japan

Source: (Kimura & Suzuki, 2006)

Examples from the literature show that FIT policy has a strong link to innovation in renewable energy technologies, technology cost reduction, technology deployment, electricity sector reform, electricity wholesale and retail price reduction, green employment, reducing carbon emissions and even the overall energy industry. Most of the studies in the literature, however, did not include an integrated assessment of the effects of the FIT that might act as a scorecard to evaluate policy outcomes and performance. Although the feed in tariff cost and its general design elements might change and be reviewed periodically to adapt to market dynamics, in this study, I argue that reviews and amendments should also consider the direct and indirect effects on other sectors, not only in the electricity sector. In addition, amendments should consider the short and long-term impacts they impose on society in general.

The motivation of this study is not only about justifying the cost of feed in tariff policy or minimizing the policy cost but also about the timing of feed in tariff support. This should be distributed temporally in an optimized way to consider technological development, its local and global cost dynamics, the supply and demand of renewable energy deployment, and the planning, development, and coordination of infrastructure.

The aim of this study was to conduct a multiple-objective impact assessment for the feed in tariff policy in Japan. The impact assessment was intended to verify that national policies are aligned to achieve a common goal, and whether the current FIT policy is helping to achieve the relevant short and long-term objectives. The interactions between policies and their outcomes were studied using the impact assessment; hence, their shortcomings could be traced and investigated. The impact assessment is especially important because decisions about energy transition, the energy mix, and the share of each energy source are mostly influenced by political rather than economic or scientific justifications. This can be clearly seen by the change in energy policies after the change of ruling political parties. The case study of Germany in this thesis shows that the energy transition process can take decades when facing various policy challenges and sometimes, public resistance.

The reasons for choosing wind and solar as the subjects of this thesis is that wind and solar are the fastest growing renewable energy technologies, and they constitute the largest share of renewable energy electricity generated in Japan. According to the International Energy Agency report, wind and solar contributed about 82% of the renewable energy deployments around the world in 2014[1] (IEA, 2015). There are several studies in which the growth of renewables are discussed, with a focus on wind and solar in particular, and their potential role in the transition to renewable energy (Campoccia et al., 2009; del Río & Unruh, 2007; Energy, 2010; Esteban et al., 2010; Hirth, 2013; Jenkins, 2015; Lew et al., 2013; Lütkenhorst & Pegels, 2014; Patel, 2005; Tsuchiya, 2012).

[1] Wind energy 56%, solar energy 27%, and other renewable energy sources 17%, excluding hydropower generation.

Power generated by wind, and solar energy has special characteristics. Both are highly variable because their generation is largely influenced by daily and seasonal weather changes. From the energy forecast point of view, both solar and wind are highly unpredictable, meaning that the output of a certain facility may drop from hundreds of megawatts to zero without early warning. Moreover, wind and solar are usually conceived as technologies that complement each other for day and night generation (i.e. solar generation reaches its peak at noon, wind energy generation peaks when cloudy or after sunset). They also complement each other in terms of the distribution of their natural resources and geographical locations. Wind turbines are usually installed in coastal and mountain areas (and some offshore areas), which have may have low solar insolation, while solar is installed over areas of flat land, or on residential and commercial rooftops. From a development point of view, these two technologies have low operational maintenance and do not require fuel (solar energy might be considered to have lower operation and maintenance costs when without moving parts. However, weather erosion, soiling, and many other issues unique to solar technology might increase the O&M cost to the level of wind turbines). There is strong opposition to the investment in the wind and solar technologies in Japan due to their high upfront costs. Whereas the technologies for harvesting geothermal and tidal wave energy are relatively mature and can generate abundant, stable electricity at much lower costs, the cost trends of solar and wind are declining at a comparatively faster pace.

The high renewable energy promotion incentives had an important role in reducing the risk of investment in new wind and solar technologies and upscaling their mass production. The rapid decline of their technological costs should make them more competitive with other renewable energy technologies in the future, and signifies their contribution to the transition to green energy. From the viewpoint of renewable energy policy, both of these technologies and their diffusion have been affected substantially by the introduction of FIT policy. Moreover, wind and solar, in particular, might face serious challenges should the government suspend policy support in the case that proper conditions, like appropriate electricity market reform, have not yet developed. For these reasons, I have found these technologies to be relevant and chose to study both wind and solar energy in my thesis.

Research Objectives and Research Questions

The aim of this study was to assess the effect the FIT policy has on supply, planning, and manufacturing, as well as on climate change and energy transition. The study was intended to fill knowledge gaps related to providing a comparative analysis, using the experience from other countries with FIT design, challenges, and renewable energy planning. In addition, this study provides answers to various criticisms of feed in tariff policy by discussing common scholarly arguments presented in the literature.

RQ0 What levels of FIT would guarantee profitable margins for PV installers in residential and non-residential installers?

According to many observers, the feed in tariff price announced for photovoltaic energy in July 2012 was the highest in the world. The Japanese Ministry of Economy, Trade, and Industry provided information that indicates 3% and 6% internal rates of return for residential and non-residential PV projects, respectively. However, critics claim that the tariff is too high, causing excessive burden on the electricity end users. In addition, the high tariff price is expected to cause a boom and bust effect for the photovoltaic market, as has happened in similar cases in European countries. Environmentalists, on the other hand, find the tariff level appropriate because it could succeed in accelerating the supply of photovoltaic projects. This question will be addressed in Chapter 3.

RQ1 By what mechanism should FIT be dynamically adjusted to cope with market dynamics in Japan?

In other words, considering cost dynamics, how should the FIT price be dynamically reduced over time? The feed in tariff cost for photovoltaic energy is currently the most expensive compared to all other renewable energy technologies. This feed in tariff price, if not optimized dynamically, could result in 1) excessive profits for the investors and project developers (the snowball effect), or 2) could increase the burden of cost sharing of the FIT program (FIT surcharges passed to electricity consumers and taxpayers). Moreover, the reducing the FIT as a reactive measure, due to information delays and or lack of proper control measures, usually results in catastrophic effects on market stability. In Chapter 4, how tariff levels should be adjusted will be discussed, according to market dynamics. Chapter 5 provides a case study for how tariff prices could be adjusted for the solar rooftop market in Germany.

RQ2 Given limited infrastructure, how should the growth of renewable energy be planned?

Despite calls for accelerating renewable energy development or increasing its share above the levels announced by the Japanese government, the limitation of the infrastructure raises serious challenges.

The growth of renewables requires various regulatory and technical reforms to the electric transmission network.

RQ3 What effect does the FIT have on innovation in the renewable energy sector?

The multiple-objective justification of promotion policies emphasizes the role of FIT policy in innovation for further technological enhancement and cost reduction. Recent literature indicates a broad range of results related to the effect of the feed in tariff on innovation. Moreover, some research suggests that feed in tariff policy encourages practical innovation for cost reduction (learning by doing) and economies of scale, rather than by radical or disruptive innovation. However, it is difficult to deduce similar conclusions for the Japanese feed in tariff policy because most of the data referred to in relevant literature are limited to the year 2011, or before. The patenting activity for renewable energy and for solar PV, in particular, is highest in Japan. In this thesis, I explore the effect of the FIT on patenting activity in Japan. This research question is answered by reviewing the patenting activity at major patent offices before and after enactment of feed in tariff policy in Japan. In addition, the patent activity of the twelve top Japanese companies was analysed.

RQ4 What effect does the FIT have on the transition to renewable energy in Japan?

The introduction of feed in tariff policy as a mechanism to achieve renewable energy targets has important impacts on the energy transition in Japan. The rapid growth of renewable energy affects the profitability of conventional energy generators and eventually affects CO_2 emissions. The possibility of achieving a transition to 100% renewable energy is discussed.

Research Methodology and Design

Overview

In this section, the research method used in this study is described, and its applicability to the research questions explained. The overall design of the thesis is explained.

Research Method

The impact assessment of this study was conducted using an integrated method of system dynamics and case studies. The research will utilize a mixed methodology that integrates the System Dynamics and Case Study approaches (Williams, 2002). Case Study (Yin, 2008) is a well-established methodology for theory building in social and management sciences. This methodology is widely used for its strength in exploring and explaining problems. Theories are developed from observing certain patterns recurring in the cases under study. It is very useful for comparative research, where there is not enough available data for the new case to be studied, which applies significantly to this research (i.e. optimizing the feed in tariff for PV energy in Japan). On the other hand, because this research involves an optimization problem, the case study methodology alone is not sufficient. It becomes essential to integrate Case Study methodology with a complementary approach that is also appropriate for solving optimization problems.

System Dynamics emerged in the late 1950s, initiated by Professor Jay W. Forrester. Since then, it has been widely employed in the area of corporate strategy design, industrial management, and economy and policy analysis. System dynamics is the optimal solution for complex and dynamic problems that involve nonlinearity, time delays, accumulations, and human intervention. It is built on the fundamental principles of mental models, feedback loops, and stock and flow modelling (Cronin et al., 2009; J. Sterman, 1994). These principles are the fruit from integrating various theories and philosophies, including General System Theory (Ludwig von Bertalanffy), System Theory and Sciences (Kenneth Boulding and Herbert Simpson), System Approach (Norbert Wiener), and (Feedback Control Theory), to name a few (Barlas, 2002).

There are many reasons why system dynamics is applicable for this research.

a. It requires system thinking that helps not only in simulating the model but also in analysing its key components and major factors and in re-diagnosing it major flaws and inefficiencies.

b. System dynamics follows policy experimentation: in which the policy model evolves as it is tested and verified.

c. The data required is sometimes unavailable, inaccurate, or in error: System dynamics allows generating a continuum of data and multiple runs to provide a considerable number of probabilistic trails.

d. Low-cost experimentation: Policy implementation is time-consuming and very costly.

The advantages of having an integrated approach are summarised in Table 0-1. Unlike the conventional complexity known as details complexity, time-delays complexity is concerned with feedback and response times. A system with feedback structures and time delays involves oscillating behaviours, and such complex behaviour makes it challenging for policy-makers to choose intuitively efficient decisions to meet their targets. Nonlinearity is another factor that increases the complexity of FIT optimization, by which a small change in the system can result in unpredictable behaviours over time (also known as chaos). However, inefficient decision making in policy results in a deviation from the targets, which in turns requires more changes and reviews for adjustment. Such policy interventions usually have side effects and unintended feedbacks, which increase situational complexity. Moreover, testing of policy is highly expensive and mostly impossible, not to mention requiring substantial time to obtain the results. Complex dynamic problems of this nature that incorporate time delays, nonlinearity, and human intervention, can be efficiently resolved with system dynamics modelling and simulation. The simulation can serve for experimentation and prototyping in the policy lab. This research uses an integrated methodology, which combines system dynamics modelling and a case study approach. The integrated methodology is well established in social and management sciences for theory building. This methodology is widely used for its strength in exploring and explaining problems.

Table 0-1: The integrated method of system dynamics and case study

	Dimension	System Dynamics (Forrester, 1961)	Case Study (Yin, 1984)	Integrated (Williams, 2002)
1	Controllability	High	Low	High
2	Deductibility	Medium	Low	Medium
3	Repeatability	Medium	Low	High
4	Generalizability	Medium	Low	Medium
5	Explorability	Medium	High	High
6	Explanatory	Low	High	High
7	Descriptiveness	Low	Medium	Medium
8	Prescriptiveness	High	Low	High
9	Predictability	High	Low	High
10	Represent-ability	High	Low	High

Source: (Williams, 2002)

Theories are developed from observing certain patterns recurring in the cases under study. It is very useful in comparative research where there is not enough data available for the new case to be studied, which applies significantly to this research (i.e. optimizing the feed in tariff for PV energy in Japan). On the other hand, because this research involves an optimization problem, the case study methodology alone is not sufficient. It becomes essential to integrate case study methodology with a complementary approach that is also appropriate for solving optimization problems.

The system dynamics model incorporates two parts: the feedback model and stock-and-flow model. Feedback loop models are part of a system thought process, which is essential for capturing the causal relationship between policy elements. It assists in understanding the problem boundaries and hence simplifies the problem size and scale, by focusing on the most relevant components of the system. The stock and flow modelling capture the numerical parts of the problem. The model, in general, is intended to simulate and optimize the photovoltaic energy feed in tariff policy. In addition, insights learned from cases studies of previous experience in Spain and Germany, provided lessons to be learned and important points to be considered in the model. The research focused on the photovoltaic feed in tariff in the Japanese market for the following two major reasons. First, photovoltaic energy is noticeably more expensive than other renewable energy technologies, and accordingly it has been given a higher level of feed in tariff compensation. This high-cost feed in tariff, however, provides a critical incentive for photovoltaic investors, developers, and operators to enter this market, especially because photovoltaic technologies are less mature and efficient in generating electricity compared with other renewable energy technologies. The high incentive has been globally observed to have a positive impact on increasing the demand for system deployments and eventually on increasing manufacturing capacity, which leads photovoltaic technologies to a rapid decline in prices. As prices decline, the feed in tariff should be adjusted accordingly. However, due to delays (referred to as information or reporting delay), these adjustments take the time to be implemented. Such delays allow profit margins to increase unreasonably, creating excessive burdens on electricity consumers. Therefore, careful and long-term plans are needed to avoid frequent policy reviews and changes, and optimization techniques are indicated. Therefore, the system dynamics simulation could be the right tool to enhance the feed in tariff policy. The second reason to study PV policy in Japan is that the PV market in Japan was highly influenced by local PV manufacturers before the implementation of FIT policy in July 2012. However, since then the case has become more challenging as the demand for energy increased substantially after the Great Earthquake of Fukushima in March 2011. The shutdown of multiple nuclear reactors created urgency for a quick energy substitute. In addition, starving foreign PV companies, which are losing markets in the United States and the European Union due to high competition and low feed in tariffs, are entering the Japanese market. Therefore, developing a policy that balances the promotion of local manufacturing and R&D, but also provides a fair policy that considers free market competition will be required.

(Awerbuch & Berger, 2003) argue that while the future scenarios modelled might not be perfectly realized in the future, they, at least, provide guidelines for understanding future patterns. The strength of this approach is that the past is a reliable guide to the future, despite exceptions. The scenarios do not guarantee that unexpected events will not happen; rather the projections are informed by past experience. System dynamics, on the other hand, does not primarily depend on patterns in the data, but more on the structural dynamics of a problem. Similarly, users of system dynamics emphasize that medium to long-term projections are highly uncertain as the structure of the problem itself, might evolve or change due to external factors. (Baumgartner & Midttun, 1987) suggests that successful modelling is not about predicting the most accurate future scenarios but rather about concluding a balanced and reasonable trade-off between affected interests. This includes assuring that all interests are well identified and represented; basic assumptions are clear, there are criteria for evaluating the fairness of the model, and that the bias of the model toward certain energy sources is understood (Baumgartner & Midttun, 1987; Makkonen, Nilsson, & Viljainen, 2015).

Research Methodology

Policy impact assessment refers to "formal, evidence-based procedures that assess the economic, social, and environmental effects of public policy" (Adelle & Weiland, 2012; EC, 2009). It is a method that aids political decision-making but is not a substitute for it because all policy decisions should be based on sound analysis. This process should ensure coherence and consistency of policies, and provide a transparent cost/benefits analysis of policy alternatives. According to the European Commission, the impact assessment should take place at an early stage of planning public policies in order to discover potential issues and mitigate with appropriate solutions (EC, 2009). The EC differentiates impact assessment as an early process that precedes policy adoption, and then monitoring and reviews of processes for guiding the assurance of policy performance and efficiency. However, later EC definition of impact assessment established it within a broader framework of "better regulation" (EC, 2015a, 2015b). The impact assessment guidelines help in answering questions related to clarifying policy problems, identifying stakeholders and their concerns, defining policy objectives and addressing them, and mitigating the economic, social, and environmental effects of policy options.

The definition of the European Commission about impact assessment is what is described as ex-ante analysis, which studies of policy impacts before implementation. This study, however, is designed to be an ex-post analysis because the policy under study has already been implemented (Nijkamp &

Blaas, 2012). Impact assessment is necessary for many reasons. First, the dynamic nature of economies and technologies, the policies designed under the assumption of stable dynamics, and current analytical models do not sufficiently represent the present dynamics of economies. Second, slow economic growth and consequent cuts in public budgets require more careful analysis of the effectiveness and efficiency of current policy options (Nijkamp & Blaas, 2012). There is many dimensions for impact assessments (intended versus unintended, direct versus indirect, and integral versus partial) (Nijkamp & Blaas, 2012). There are aspects of policy impact assessment that are often neglected, namely the "fuzzy nature" of policies and the "role of uncertainty". The fuzzy nature of policies refers to the interaction between the policy objective on one hand and the policy instruments on the other.

Assessment becomes significant due to the long interval after the introduction of the feed in tariff that is needed to achieve far-reaching impacts. Although the European Commission suggests that assessment should be done in an early stage of policy planning, many challenges will be unforeseeable before the implementation of the policy because market response cannot be perfectly modelled or predicted. In addition, learning lessons from other countries (case studies) might provide ways to explore potential policy weaknesses. Moreover, the multiple occurrences of certain patterns would provide stronger evidence for policy makers to reassess the policy impacts. There are several studies in which feed in tariff policy assessment, and evaluation after policy implementation, was conducted.

The impact assessment is derived from the analysis of global experience in Europe and the United States. This does not mean that the criteria for assessment and goals must be identical to those in other countries. However, a comparative analysis of the cases might be helpful to shed light on potential areas to be further studied and investigated. This also does not suggest that past patterns found in other countries will occur in Japan, or that the energy transition process will require the same amount of time in Japan. Nevertheless, the similarities in the system structure of the problem are expected to produce similar outcomes, and hence provide useful lessons to learn from, and to apply in Japan. For example, unlike the policies implemented in Europe, the United States, or Canada, the current feed in tariff policy in Japan does not have clear objectives for green employment or supporting local manufacturing. Therefore, assessing the outcome of an important policy like the feed in tariff should be provided to benchmark and track policy achievements in reaching policy goals and targets amid conflicting private, corporate, and political interests.

The assessment significance can be visualized when considering the effects the policy has in other sectors. Moreover, a causal analysis is needed to understand the cascading effects and what other possibilities might occur, as well as to provide feedback loops that are invisible due to bounded rationality. Research suggests that decision makers are usually biased to favour their own cognitive perceptions and short-term effects and that they neglect inputs and long-term impacts that are outside their knowledge domains. Feedback effects do not occur instantly but as a response to the initial policies implemented. For example, the introduction of renewable energy under the merit order scheme (which gives priority to renewables) had a great effect on reducing wholesale electricity prices, especially during peak demand. This has made the electricity from renewables like wind, and solar far more favourable than the electricity generated from LNG gas, and some coal power plants went out of business. This effect has led to the accumulation of global stocks of coal, and significantly lowered its price. In response, coal power plant owners find an opportunity to compete against renewables using lower-cost coal and reducing their margin to remain competitive. As a result, the supply of electricity from the combustion of coal has increased significantly, causing more CO2 emission. This feedback dynamic that will be discussed in detail, and is a major flaw of the feed in tariff policy impact assessment. Although the decisions governing the energy mix, the energy sources, and their shares reach beyond the feed in tariff policy, their outcomes may contradict feed in tariff policy goals and objectives. Moreover, the impact assessment in this study was intended to explain how to make sure that feed in tariff policy achieves its intended objectives. System thinking and system dynamics has been used for impact assessment (Anand, Vrat, & Dahiya, 2006; Hsu, 2012; Ozolins & Kalnins, 2006; Shen, Wu, Chan, & Hao, 2005; van Geenhuizen, 2010, p. 205).

Ever since the German FIT policy or EEG was announced, the research of renewable energy policy has gained dramatic momentum. Previous research presented analyses of FIT pricing policy from a mathematical modelling perspective (Andor, Flinkerbusch, Janssen, Liebau, & Wobben, 2010; del Río, 2012; Kim & Lee, 2012). Mathematical analysis and modelling usually lack analysis of the systematic behaviour between the FIT policy and PV industry responses. Understanding this policy-market behaviour should provide the basic factors that mainly influence the FIT policy as a system. Once these factors are captured and modelled, it should be feasible to apply different "what-if" scenarios that could improve and optimize the FIT policy. This research could be done using the System Dynamics approach. So far, as is known, no comprehensive previous research has been done using System Dynamics to analyse the FIT for the PV industry.

Applicability of the System Dynamics Method in this Research

It is important to demonstrate the reasons for selecting system dynamics as the preferred method. Here, system dynamics is compared with other prevailing techniques used for energy modelling. In general, energy models can be classified into three categories according to the technique used to solve the problem: optimization models, equilibrium models, and simulation models (Ventosa, Baıllo, Ramos, & Rivier, 2005). In addition, energy models can also be classified according to the way model elements are structured: bottom up and top down models (Enzensberger, 2003).

Energy models are used for different applications. Some of these are for projecting energy supply and demand, assessing economic and environmental impacts, and studying policy options and their implications (Van Beeck, 1999). The applicability of SD models for electricity market modelling has been described in detail (Adelino J.C. Pereira & Saraiva, 2013; A. J. C. Pereira & Saraiva, 2009; Sanchez, Bunn, Centeno, & Barquin, 2009). It is, of course, possible to analyse energy models using statistical models; however, there are some shortcomings to the statistical viewpoint. When system dynamics is compared with econometrics, SD provides more reliable forecasts over short to medium term than make statistical approaches and so it leads to better decision-making. It also provides means to identify key sensitivities within the system, providing scenarios that are more sensitive. Moreover, system dynamics provides means for calibration to historical data; so its forecasts minimize the risk of uncertainties (Lyneis, 2000; J. Sterman, 2002; J. D. Sterman, 2000).

System dynamics is not intended to work as an optimization technique. This is because optimization functions tend to find the best answer in the future and then look back on all variables trying to find the optimal solution. Moreover, the decision-making process always assumes perfect knowledge seeking for the optimum answer. In contrast, the system dynamics perspective is always forward towards a moving target, which is more realistic, as decision makers take actions based on past calculation towards strategic objectives (Grobbel, 1999). Furthermore, decision making, in reality, is built upon expectation over time rather already known perfect answers. The delay before and after decision-making is another important aspect that is considered in system dynamics. There is a delay in constructing the perception of a certain problem, as the time needed to investigate an issue, collect information, and report it to management. There is also a delay in taking action, during which the effect of the actions taken can be observed. It is important to account for these time delays when considering that changes to the existing problem might occur while it is being solved, which makes it a dynamic problem (Cronin et al., 2009; Forrester, 1961; J. D. Sterman, 2000).

Input-output models use several departmental models, which are integrated by linking the input and output of each department to the other. These models have to be matched in an iterative way. The process tends to be time-consuming and might result in an inconsistent model; whereas the system dynamics method is consistent by definition. A simple input-output model is given below (Ventosa et al., 2005). System dynamics is a method that combines both the qualitative analysis of system thinking and causal feedback loop analysis, in addition to quantities analysis represented in the mathematical modelling using stock-flow diagrams. One school of thought emphasizes that system dynamics is a theory building process (Kim 2014), a learning tool (J. D. Sterman, 2000), or primarily a qualitative method that is supported using quantitative analysis (Yamaguchi, 2013)

Table 0-2: Classification of energy modelling methods

Category	Type	Description	Examples
Top Down	Optimization models	Also called partial models, focus on certain sectors of the economy.	Linear Programming, Nonlinear Programming Models
	Simulation models		System dynamics and agent-based modelling
Bottom Up	Equilibrium models	Have macroeconomic model development and perspective within the entire economy	Input-output model
		Requires higher level of aggregation	Computable General Equilibrium Models (CGE)

Table 0-3: Example of an input-output model

Input	Output
Electricity demand	Electricity price (spot price and average price)
Fuel prices	Production capacity per energy
Investment-dependent and variable costs	Produced quantities of electricity per energy
Feed in tariffs, CO_2 taxes	CO_2 emissions
Capacity and transit time of nuclear power plants	

An investigation of earlier energy models has found that the results of quantitative models deviate from those of their qualitative analysis. This is partly because future trends deviate beyond near-term future because the quantitative assumptions are no longer valid. Qualitative system analysis demonstrates the potential value of understanding the future for suggesting possible patterns of system evolution, and for identifying areas of potential vulnerability in system models (Forrest, 2006).

Because the electricity generation system is extremely interrelated in all parts, a dynamic modelling approach seems appropriate in order to get an overall understanding of competition in the field. SD provides a holistic understanding of the electricity generation industry in a competitive market situation and during the transition phase. The human brain cannot handle more than five to seven variables influencing each other simultaneously (termed bounded rationality). When mental models are expressed using a computer model, we might find that our vision was completely wrong and that it could not possibly work in the way we imagined. The ability of system dynamics approaches to incorporate feedback loops is the most relevant difference between other modelling techniques Physical, and nonphysical variables can be modelled, for example, experience, learning and which is another shortcoming of linear models. System dynamics represents information delays because decision makers cannot access information immediately. The system dynamics model attempts to approach reality as much as possible by incorporating all relevant and key feedback loops. Complexity and interdependence between variables can be documented and shown graphically to identify key (most influential) variables. System dynamics allows managers to experiment with alternative assumptions, designs and policies (Barlas, 1994). The DOE (1993) documented the major milestones of SD models in the fields of energy and power industry. Others (Teufel et al., 2013) compiled a comprehensive and updated review of more than 80 SD models.

Research Design

The study will commence by introducing the literature and key concepts of renewable energy sector in general. Then it will introduce the development of renewable energy and renewable energy policies in the Japanese market and compare it with other major markets in Europe. After that, a general conceptual frameworkWill be introduced to investigate policy interaction with the key elements in the market and how a sensible policy can be modelled. Next, the profitability and sustainability of the feed in tariff policy will be evaluated using profitability analysis for the residential and non-residential solar energy projects. This will be supplemented by another model which aims to study the cost development patterns and design a responsive tariff pricing policy which copes with market dynamics and reduces policy budget costs. Due to the limited data available on the market in Japan, the model was applied to a case study of the German residential solar market. After evaluating on financial impacts of feed in tariff, further assessment will be conducted about the impact of the future growth of renewable energy under the limitation of the infrastructure capacity of the electric network. Then, the policy impact on the renewable energy innovation activity in Japan will be discussed. Finally, the study will then discuss the policy impact on overall energy transition and climate change mitigation. The research was composed based on the publication indicated in Table 0-4.

Table 0-4: Publications in thesis

Paper	Conference/Journal	Paper Status
Designing Photovoltaic Feed in Tariff Policy Based on Market Dynamics: The Japanese Market as an Example	The 2014 Asia-Pacific System Dynamics Conference, Tokyo, Japan	Published
Dynamic Feed in Tariff Price Adjustments for Roof-top PV Market in Germany	International System Dynamics Conference, Boston, MA, USA 2015	Published
Modelling the renewable energy development under limited transmission network in Japan	International Symposium on Operation Management and Strategy 2015, Tokyo, Japan	Published
Impact Assessment of Feed in Tariff Policy on Renewable Energy Technology Innovation in Japan	Journal of Law, Technology and Public Policy, JLTPP 2015	Submitted
Analysis of Feed in Tariff Policy Impacts on Energy Transition and Climate Change Mitigation in Japan	Journal of Law, Technology and Public Policy, JLTPP 2015	Submitted

Data sources

The data used in the thesis was obtained from a broad range of sources. These included attendance at international conferences and seminars including the Intersolar Conference and Exhibition in Munich Germany, the International System Dynamics Conferences (ISDC 2013 in Cambridge MA, United States and ISDC 2014 Delft, The Netherlands), the Asia Pacific System Dynamics Conferences (Tokyo, Japan) the International Symposium Organization Management and Strategy (ISOMS 2015 in Tokyo, Japan), the PV Expo exhibitions in Tokyo and Osaka, and the World Future Energy Summit in Abu Dhabi, United Arab Emirates. Moreover, extensive data about the Japanese market were obtained from the Ministry of Economy Trade and Industry, National Policy Unit of the Cabinet Secretariat, and Japanese independent NPOs like Japan Renewable Energy Foundation, Greenpeace, and Wild World Foundation Japan (WWF Japan). Comparisons with other markets were based on data from journal articles and recent market reports. For solar photovoltaics, PV module manufacturing data and deployment capacities were obtained from the Japan Photovoltaic Energy Association, Japan Wind Power Association, and German Photovoltaic Industry Association. The updated feed in tariff statistical data have been achieved from the METI website dedicated to feed in tariff statistics. Some information was used from the Strategy Policy Unit calculations, which provide detailed information about the cost of generation for all energy sources used in Japan. Solar data were obtained using PVSyst software, which incorporated satellite data.

Testing and Validation

System dynamics models are intended to produce useful insights based on robust, well-tested models. The models are tested at several levels, the first of which is logical testing. The causal loop diagrams (CLDs) test the causal relationship and logical connectivity between the parameters used in the model. Thus, CLD analysis is qualitative study intended to reveal the underlying factors that cause a certain phenomenon. The testing processes include testing the model against extreme values and avoiding physical stocks from being unrealistically negative. An example of that would be a bathtub used to store water. In the well-tested system dynamics model, the bathtub could never have negative water levels. In addition to these tests, usage cases should be prepared to validate the intended rationality. This means that the model not only functions normally without physical errors but also operates logically in the way expected. Because models are a simplification of reality, models are evaluated not based on their accuracy but rather for the purposes for which they were developed. It should be noted that the purpose of the model and its objectives should determine the boundary of the model, its level of details and abstraction, and its accuracy. Models should be used mainly as learning tools to understand the structure configuration of the problem under study and to analyse the impact of different policy scenarios. Cautious use is suggested because the quantitative results might not be accurate (Sterman, 2002). System dynamics helps to understand the behaviour generated from the structure. The model does not aim to provide exact and accurate data because the system dynamics approach is not concerned with a high level of granularity. However, useful insights about strategies and directions can be obtained by its use.

Modelling Guidelines and Standards

The modelling in this dissertation follows the modelling guidelines and standards suggested by the System Dynamics Society. The guidelines include a naming convention, diagramming standards, and documentation (Rahmandad & Sterman, 2012). The modelling standards help in research reproducibility and future reusability in future studies.

Thesis Outline

The thesis is broken down into eight chapters. Chapter 1 explains renewable energy promotion policies with emphasis on the feed in tariff policy and its design elements. It also provides a comparison with other policy alternatives, like the renewable energy portfolio standard (RPS). From this FIT foundation, Chapter 2 proceeds to demonstrate the impact of feed in tariff policy on renewable energy development in Japan and illustrates two case studies of photovoltaic (PV) markets, one from Spain and another from Germany. Chapter 3 provides a profitability assessment for individual solar projects in Japan. It compares the policy in years 2012 and 2013. Chapter 4 provides some understanding of the major challenges to developing the renewable energy market under the feed in tariff policy. It illustrates the effect of the feed in tariff price on the sustainability of renewable energy businesses. Chapter 5 discusses the impact of the FIT on the dynamics of renewable energy supply and on achieving the national targets. It includes a detailed simulation model of solar photovoltaic deployment growth (residential rooftop solar market in Germany). The model recommends a dynamic adjustment to the feed in tariff cost. Chapter 6 reports the results of an investigation of the long-term effect of feed in tariff policy on renewable energy supply while considering infrastructure planning and expansion. Chapter 7 explains how the feed in tariff policy influences innovation in the solar and wind power technologies in Japan. Finally, Chapter 8 presents an assessment of the long-term policy effects on the energy transition and climate change processes in Japan, as compared with those in Germany.

1 Renewable Energy Policy

Overview

In this chapter, the rationale for government intervention is discussed, along with the objectives of renewable energy promotion policies. It then explains the feed in tariff policy and its design elements. After that, the key economic concepts on which the feed in tariff policy depends on are explained. Next, the policy calculation method will be explained. Finally, a comparison with other major policies, such as the renewable energy portfolio standard (RPS) is provided.

1.1 Rationale for Government Intervention

Government intervention versus free market will is an old debate in the literature. Recent researchers believe that government intervention is justified because it provides correction of market failures (i.e. the external cost of fossil fuels) (Nogee, 1999). Other researchers emphasize that it is necessary to allow market dynamics to shape market development and prevent failures of costly government interventions (Menanteau, Finon, & Lamy, 2003; Taylor & Van Doren, 2002). These two fundamental views resulted in the development of two different approaches to promoting renewable energy policies, namely the quantity based and price-based approaches. The quantity-based approach has materialized in the form of the renewable portfolio standard policy (RPS) under which the quantity of renewable energy is determined first, and then through market competition via mechanisms such as bidding or auctions, the price for this quantity is determined. This requires that power generators produce certain quotas of renewable energy. The RPS policy has been found very suitable for the development of large-scale power plants because auction processes allow cost efficiency. On the other hand, the price-based approach materialized in the form of the feed in tariff policy. Under this policy, regulators determine the tariff price per kilowatt-hour (referred to as USD/kWh) or megawatt-hour (USD/MWh) for a quantity that is to be determined by market competition. Unlike the RPS policy, the feed in tariff policy provided higher visibility and lower investment risks, in addition to guaranteed fixed returns on investments.

Another major segment of the literature has been concerned with the evaluation of different instruments to promote renewable energy (Ackermann, Andersson, & Söder, 2001; Klein, Held, Ragwitz, Resch, & Faber, 2007; Langniß, Diekmann, & Lehr, 2009; Ragwitz et al., 2007). Despite extensive research, neither policy has been found more effective than the other has, and therefore in many cases both policies are used in the same country.

Deciding the period of subsidization in the policy design is a critical factor for achieving the policy objectives. However, policymakers also have to decide whether these incentives favour achieving private objectives or social objectives. Long-term purchase agreements, for example, have an important role in the diversification of the energy mix. Long-term purchase agreements provide an incentive for investors to invest in technologies that are capital intensive but with the lower risk associated with fuel prices, such as with nuclear or renewable energy. In the absence of long-term power purchase agreements, it has been found that optimal investment portfolios of private investors differ greatly from portfolio investments driven by social benefits because energy diversification has little innate value to private investors (Roques, Newbery, & Nuttall, 2008).

What are the current policy evolution methods that are used and how robust are they? (Edenhofer, Hirth, et al., 2013) identified several criteria: 1) the ability to identify many of the key interactions between the energy system components in addition to the economic and climate systems, 2) the use of economic measures for endogenous model decision making, 3) the use of a long-term horizon that scales up to multi-regional actions, and 4) the mitigation of policy risk (Edenhofer, Hirth, et al., 2013; Krey & Clarke, 2011).

1.2 Feed in Tariff Policy

The feed in tariff policy is renewable energy that aims to accelerate the investment in renewable energy. Some policy makers argue whether the feed in tariff should be used for small generators only while other alternative mechanisms (e.g. competitive biddings and auctions) should be used for large-scale generation projects (Deutsche Bank, 2009). Based on this discussion, the feed in tariff policy in some countries includes a cap limit of the maximum project capacity. In Spain for example, a 50 MW cap was used, while in the United States, a 20 MW cap was used.

Renewable Energy policy formulation requires several factors to ensure its success. The Brookings Energy Security Initiative recommends that "[c]ountries must set objectives and develop consistent, durable and clear national policies to manage the complexity of large-scale renewable energy integration" (Ebinger, Banks, & Schackmann, 2014). It is also referred to as transparency, longevity and certainty (TLC) by Deutsche Bank Climate Change Advisors (Deutsche Bank, 2009).

1.2.1 Comparison of the Feed in Tariff and other Policies

There is an extensive literature focused on comparison of the feed in tariff and other renewable energy promotion policies like tendering schemes, net metering, and the renewable portfolio standard (Butler & Neuhoff, 2008; Cory, Couture, & Kreycik, 2009; Couture, Cory, Kreycik, & Williams, 2010; Davies, 2012; Dong, 2012; Grau, 2014a; K Won, 2015; Marschinski & Quirion, 2014; Menanteau et al., 2003; Ritzenhofen, Birge, & Spinler, 2014; Sun & Nie, 2015, 2015; Taha & Daim, 2015; Yamamoto, 2012).

1.2.2 Feed in Tariff Cost Calculation Methods

There are two calculations used to determine the cost of the feed in tariff: the first is based on the generation cost of electricity, and the second is based on the avoided costs of fossil fuels. Most European countries that have adopted a feed in tariff policy use the calculation based on the generation costs with an added margin. The feed in tariff calculation method based on generation cost typically targets a certain internal rate of return (IRR) to attract investment and reduce the level of risk. The avoided cost method, on the other hand, represents the value of new generation to the utility and has been used in California. This method determines the tariff value by calculating the value of electricity generated by natural gas during peak demand hours. Nevertheless, the avoided cost calculation has not been found effective because it does not guarantee recovery of the project investment costs (Deutsche Bank, 2009).

The setting of IRR targets for the feed in tariff varies from one country to another. It also depends on the renewable energy technology and project size. In general, IRR levels usually vary in the range 3–10%. Ontario, for example, has 11% of after tax IRR, while the French feed in tariff set 8% IRR before the tax on profit. The Dutch feed in tariff does not have a generic IRR level but provides a custom calculation depending on the cost of capital and equity return assessment. Wind energy projects, for example, can have an IRR of 15%. Another calculation of feed in tariff IRR depends on the level of risk, as in Spain and Germany. The advanced Spanish feed in tariff system adjusts the IRR based on the risk level associated with capital-intensive projects, as some projects demand more investment. In addition, the IRR in Spain is also adjusted depending on how far the renewable energy technology is from reaching the national efficiency and capacity targets.

Table 1-1: Classification of renewable energy promotion strategies

		Direct		Indirect
		Price driven	Quantity driven	
Regulatory	Investment focused	Investment subsidies	Tendering system for investment grants	Environmental taxes Simplification of authorization procedure Connexion charges Balancing costs
		Tax credits		
		Low-interest soft loans		
	Generation based	Fixed feed in tariffs	Tendering system	
		Fixed premium system	Quota obligation based on tradable green certificates	
Voluntary	Investment focused	Shareholder programs		Voluntary agreements
		Contribution programs		
	Generation based	Green tariffs		

Source: (Gawel & Töpfer, 2013; Reinhard Haas et al., 2011)

In Germany, the IRR is set between 5 and 7%, relatively lower than in other countries, in order to minimize the cost yet provide a reasonable incentive (Taha & Daim, 2015). The IRR in Japan is set between 3.2% and 6% for photovoltaic, which is way lower than the examples mentioned earlier, yet these levels resulted in a high initial tariff set at 48 yen/kWh (METI, 2013).

The European Commission in January 2008 issued a directive calling for increased renewable energy targets in all of the 27 member states (with a minimum 5% increase) in order for the European Union to shift from 8.5% to 20% by the year 2020. Member states are expected to achieve their interim targets: 25% by 2012, 35% by 2016, and 65% by 2017 (Droste-Franke et al., 2012, p. 27). rs (FITs) are the most widely used policy in the world for accelerating renewable energy (RE) deployment, accounting for a greater share of RE development than either tax incentives or renewable portfolio standard (RPS) policies (REN21 2009). FITs have generated significant RE deployment, helping bring the countries that have implemented them successfully to the forefront of the global RE industry. In the European Union (EU), FIT policies have led to the deployment of more than 15,000 MW of solar photovoltaic (PV) power and more than 55,000 MW of wind energy between 2000 and the end of 2009 (EPIA 2010, GWEC 2010). In total, FITs are responsible for approximately 75% of global PV and 45% of world wind deployment (Deutsche Bank 2010).

Table 1-2: Renewable energy targets in selected EU member states

Country	Renewable Energy Target	
	by 2005 (%)	by 2020 (%)
Austria	23.3	34
Finland	28.5	38
France	10.3	23
Germany	5.8	18
Italy	5.2	17
Latvia	32.6	40
Spain	8.7	20
Sweden	39.8	49
The Netherlands	2.4	14
United Kingdom	1.3	15

Source: (Droste-Franke et al., 2012, p. 27)

Countries such as Germany, in particular, have demonstrated that FITs can be used as a powerful policy tool to drive RE deployment, and help meet combined energy security and emissions reduction objectives (Germany BMU 2007). This policymaker's guide provided a detailed analysis of FIT policy design and implementation and identified a set of best practices that have been effective at quickly stimulating the deployment of large amounts of RE generation. Although the discussion was aimed primarily at decision makers, who had decided that a FIT policy best suits their needs, exploration of FIT policies can also help inform choices among alternative renewable energy policies. This paper builds on previous analyses of feed in tariff policy design, most notably by (R. Haas et al., 2004; Held & Ragwitz, 2006; Mendonça, 2012a; Ragwitz et al., 2007). It also provides a more detailed evaluation of a number of policy design options than is currently found elsewhere in the literature. This report considers both the relative advantages and disadvantages of various design options for FITs. Drawing on the literature cited above, this paper explores experience with feed in tariff policies from the European Union, where the policy has been used for approximately two decades, as well as recent examples of FIT policies in Canada and the United States. The focus on the previous implementation provides valuable lessons for FIT policy design that could help improve future policy application. A feed in tariff drives market growth by providing developers with long-term purchase agreements for the sale of electricity generated from RE sources (IEA 2008; Menanteau et al. 2003). These purchase agreements, which aim to be both effective and cost-efficient, typically offer a specified price for every kilowatt-hour (kWh) of electricity produced and are structured with contracts ranging from 10 to 25 years (Klein 2008, Lipp 2007). In order to tailor FITs to a range of policy goals, the payment level can be differentiated by technology type, project size, resource quality, and project location. The payment levels can also be designed to decline for installations in subsequent years both to track and to encourage technological change.

As an alternative to a fixed tariff level, FIT payments can be offered as a premium, or bonus, above the prevailing market price (IEA 2008, Rickerson et al. 2007). Criteria for judging the success of feed in tariffs depend on the policy goals of the jurisdiction. In the EU, national energy policies are evaluated against a comprehensive set of objectives laid out in EU-wide Directives, and include (among others) long-term RE targets, increased economic and export market opportunities, sustainable job creation, the enhanced use of forestry and agricultural wastes, and the expansion of innovative RE technologies (see European Commission, 2009/28/EC).

Naturally, different jurisdictions may have different objectives, or may attribute different strategic importance to the same goals. This notwithstanding, it is a common goal of FIT policies in both the EU and around the world to encourage RE deployment. Successful feed in tariffs can, therefore, be understood as policies that encourage rapid, sustained, and widespread RE development. FIT policies typically include three key provisions: (1) guaranteed access to the grid; (2) stable, long-term purchase agreements (typically, 15–20 years); and (3) payment levels based on the costs of RE generation (Mendonça 2007). In countries such as Germany, they include streamlined administrative procedures that can help shorten lead times, reduce bureaucratic overhead, minimize project costs, and accelerate the pace of RE deployment (see also de Jager and Rathmann 2008). Many European countries have committed to using FIT policies to achieve their long-term RE targets out to and beyond 2020, which indicates a long-term commitment. In addition, European policies typically extend eligibility to anyone with the ability to invest, including — but not limited to — homeowners; business owners; federal, state, and local government agencies; private investors; utilities; and non-profit organizations (Mendonça, 2012a). The following sections provide an overview of FIT payment design options, FIT implementation options, and various approaches to funding the policy.

1.2.3 Review of Renewable energy support policies around the world

Overview

In the following section, the evolution of renewable energy support in some of the major global markets that witness exponential growth is discussed. This illustrates the incremental policy innovation and sheds light on some major policy shortcomings. Finally, suggestions are made as to how these policies can be improved theoretically, using system dynamics analysis.

Case studies show that some major markets have exponential growth that helped to quickly achieve the targets set. Although exponential growth has positive marketing effects for attracting foreign direct investments, green job growth and carbon emission reductions, it seems that such patterns are unexpected, according to national strategic plans, which show the lack of coordination between stakeholders concerned with the renewable development plan. Such exponential growth reflects a rush to install that is aimed at rapid commercial benefits from the opportunity provided by the high, quick, and guaranteed profitability levels ensured by the feed in tariff policy. In other words, this growth pattern was actually uncontrolled behaviour that induced policymakers to take reactive measures with interventions that negatively affect the market and industry. The sudden halt of renewable energy growth in Spain, Italy, and the Czech Republic, is good evidence that the policies implemented there were not sustainable in creating a local manufacturing industry or creating green jobs.

1.3 Feed in Tariff Policy Evolution

Scholars argue about the essence of policy. Some scholars state that “there is nothing new under the sun”, and that policies are mainly integration and recombination of existing policies (Berry, 1990). Another group of scholars suggest that policies can be entirely new, where the first occurrence of the policy can be identified (Sabatier & Weible, 2014). In any case, policies could be neither incremental changes, nor entirely new, but a combination of both, developed through a long series of trial and error (Jacobs, 2014; Sanger & Levin, 1992).

The evolution of the feed in tariff can be explained in three major phases, The Public Utility Regulatory Act (PURPA) in California in 1978, then the adoption of the first German FIT policy in 1990, and finally the amendment of the FIT schemes in Spain in 1997 and Germany in 2000 (Jacobs, 2014). The policy continued to be improved with a series of other amendments; however, the three phases to be explained summarize the major development that led to exponential growth. In these phases, the priority of renewable energy purchase, tariff price, and duration of the contract were formulated to favour renewable energy development.

The PURPA act in the United States was primarily concerned with the cogeneration of energy. However, part of the law package introduced was related to renewable energy. At that time, the tariff for renewable energy was far too low for successful renewable energy projects. However, the sudden increase in oil and gas prices led to a reconsideration of the tariffs and increasing them to an effective level. In the second phase, the feed in tariff policy was adopted in Germany amid calls for nuclear phase-out after the Chernobyl accident in the 80s. National programs like the '1000 roofs', and '100,000 thousand roofs' were implemented to increase the share of renewables.

In the third phase, however, tariff pricing was an issue as Germany was going through electricity liberalization. At that time, the tariff price for renewable energy was indexed to the retail price of electricity. However, market liberalization and open market trading allowed high variability in electricity prices, which led to excessive profits for renewable energy developers. To overcome this inequity, the tariff price was fixed for the contract period. The tariff price was reduced using a degression ratio in every policy revision to reflect technological cost and efficiency changes. The default degression rate was set at 5% annually and was then supplemented with a capacity corridor concept. It is worth mentioning that the policy innovations happened under certain circumstances that included geopolitical conditions. The policy has been implemented under the influence of many goals and motivations. It took several decades for the policy to mature to its current stage. Although the policy is implemented in various countries, special care is needed to make sure that the policy meets its local objectives. The third phase in Germany was a significant step to which is attributed the wide acceptance of this policy around the world. It included three important reforms by which the industry could grow exponentially.

In the first reform (2000–2009) the FIT policy was focused on domestic scale up of the renewable energy generation. It also aimed at making the solar photovoltaic cost more competitive through the transparency, longevity, and certainty initiative that helped investors gain trust. In this phase, the feed in tariff degression rate was minimal, and it was carried out at regular intervals. The second reform (2009–2011) had to deal with the rapid decline of the cost for solar photovoltaic, and so required more frequent changes to the FIT price. In addition, in order to manage the annual supply of PV power, the feed in tariff degression was linked to the volume of solar photovoltaic installations and the feed in tariff policy was reviewed more frequently to keep up with market changes. Because the cost of renewable energy technologies like solar photovoltaic, wind and biomass became competitive with conventional energy, in the third reform (2012–present), more feed in tariff reductions were introduced, as well as a market threshold of 52 GW (Deutsche Bank, 2012a).

The important factors behind the success of the feed in tariff policy as explained by (Scheer, 2013) are described using the causal loop diagrams below.

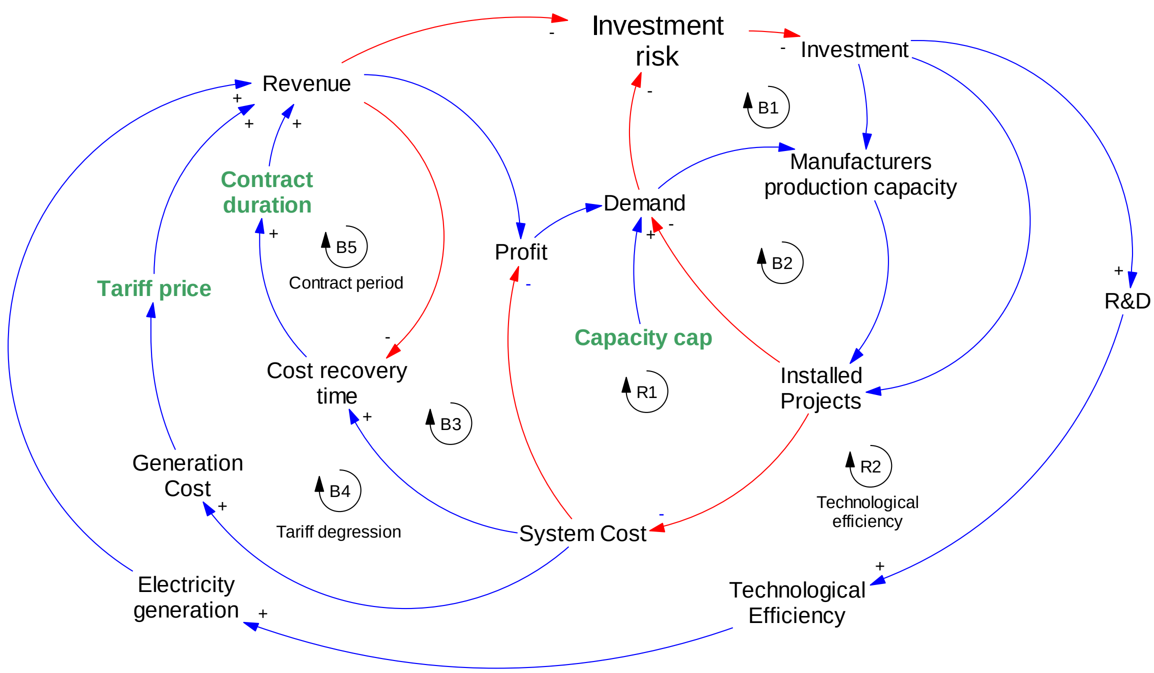


Figure 1-1: Factors behind the success of the feed in tariff policy

Note: In system dynamics and system thinking literature, R refers to the term Reinforcing feedback loop, it is also called a positive feedback loop, while B refers to Balancing feedback loop, of negative feedback loop. Source: Author's drawing

1.4 Renewable Energy Promotion and Policy Objectives

Clearly identifying the objectives of a renewable energy policy is indispensable for its success. According to Edenhofer "By definition, the economic potential is not only a function of techno-economic assumptions, e.g. expectations on technology learning but also hinges crucially on the prioritization of underlying and potentially competing for public policy objectives" (Edenhofer, Hirth, et al., 2013). The authors also suggested a public policy framework constituted of three major and interrelated factors 1) multiple public policy objectives, 2) multiple externalities (positive and negative), and 3) multiple policy instruments (Edenhofer, Seyboth, Creutzig, & Schlömer, 2013).

1.4.1 Energy Security

Energy security is about the uninterrupted supply of energy services (Johansson & Nakićenović, 2012) or robustness against unexpected disruptions of energy supply (Arvizu, Bruckner, et al., 2011, p. 120). Energy security incorporates various aspects of resource availability and resource distribution, as well as the reliability of the energy supply (Edenhofer et al., 2011). These can be assessed and measured by the degree of global dependency of the import/export balance, or by the level of diversity and resiliency of the energy mix (Johansson & Nakićenović, 2012). A resilient policy would ensure the stability of energy supply in case of unexpected disturbances. For example, energy policies that largely dependent on oil imports can be impacted sharply by fluctuations of oil supply or prices. Moreover, energy policies in which nuclear energy is dominant can be destabilized by nuclear accidents. Although renewable energy can enhance energy security by replacing some portion of conventional energy production (e.g. coal and gas), in the case of countries where fossil fuel resources are abundant (like the United States or China), the deployment of renewable energy had little impact on energy security. Therefore, it is argued that the comparative advantage of renewable energy lies with environmental benefits and not significantly with energy security (Borenstein, 2011). In fact, large shares of renewable energy might have negative impacts on energy security if appropriate measures were not in place (Arvizu, Bruckner, et al., 2011).

1.4.2 Clean Energy Jobs

There is also discussion in the literature about the role of renewable energy in creating green jobs. Subsidizing renewable energy development is justified because it can stimulate job creation in the short term, and in the long term by supporting domestic economies (BMWi, 2014; Borenstein, 2011; Fraunhofer, 2014). However, over both the short and long term, such studies ignored comparison of alternative policy options and, therefore, their results might be regarded as unreliable (Edenhofer, Hirth, et al., 2013). For example, the capacity of PV installations in Germany has doubled about four times between 2008 and 2010, yet panel manufacturing declined 77% from the capacity in 2008 to around 27% in 2010 due to the outsourcing of production facilities to East Asian countries like China and Taiwan (Borenstein, 2011). Based on this, (Edenhofer, Hirth, et al., 2013) concluded that renewable energy can be supported and subsidized only when 1) the social return on investment is greater than the private companies financial return on investment, and 2) when renewable energy has a lower investment when compared with other energy technologies. In other words, support for renewables should be justified with reference to its social impact.

1.4.3 Green Development

Renewable energy development is also justified for green development (i.e. increasing the GDP and reducing GHG emissions). Carbon pricing policies like ETS have been widely used for climate change mitigation (Dominique, Janssen, & Petitet, 2014; EC, 2015c; Kemfert, Opitz, Traber, & Handrich, 2015; Susan, 2007). Yet, the ETS which is implemented in 30 European States (EC, 2015d) was considered a failure because it had not ensured policies that increased investments in low carbon technologies. On the other hand, direct subsidies to renewable energy can generate technological and cost innovations that ultimately ensure that the renewable energy share becomes dominant in the energy mix (Farmer & Trancik, 2007). Several studies have carried out cost comparison of different policies and are in favour of renewables support against carbon pricing (Fischer & Newell, 2008). However, such studies neglect the supply side response and the reaction of fossil power plant owners. The increase of renewable energy share can reduce the wholesale price of electricity much more than fossil fuels like coal and gas. This makes an investment in renewables more favourable while significantly reducing the profitability of fossil fuel-based power generators. Consequently, the large supply and low demand for fossil fuel can further reduce its prices to make it relatively competitive. Fossil-based power producers might be able to resume operation, albeit at a reduced profit, resulting in increased carbon emissions. Policymakers might further subsidize renewable energies until their costs are lower than fossil fuel extraction costs. Substituting carbon pricing with renewable energy subsidies only to reduce the carbon emissions will be very costly and is considered flawed analysis because it excludes the contribution of supply-side dynamics (Edenhofer, Hirth, et al., 2013).

1.4.4 Climate Change Mitigation

When it comes to justification of renewable energy development, the mitigation of climate change externalities from fossil fuel was the primary argument. However, recent policy development and public debates have brought attention to various previously unexplored policy objectives, what is being called “positive physical side effects” which might include for example, creating green jobs, green development, reducing greenhouse emissions and environmental damage, increasing energy security, reducing poverty and addressing other sustainability concerns (Edenhofer, Hirth, et al., 2013).

1.5 Feed in Tariff Design Options

Policymakers interested in creating FIT policies need to consider a number of options. These choices include how to structure the FIT payments, as well as whether and how, to differentiate them (e.g. by technology, the size of the project, quality of the resource). As an initiative to reduce carbon emissions, the European Commission enacted mandatory reduction ratios by certain target dates. The initiative also included achieving national renewable energy targets by certain dates. In renewable energy policy design, increasing the renewable energy target is achieved by diversified energy sources. Each renewable energy source will have a certain percentage to achieve, of the total renewable energy target. The percentages vary depending on RET maturity, efficiency, and cost. Therefore, the carbon emissions reduction and consequently renewable energy capacity target both might be considered within the design and structure of feed in tariff policy.

There are four main approaches used to set the overall FIT payment to RE developers. The first is to base the FIT payments on the levelized cost of RE generation, and a targeted return (typically set by the policymakers or regulators). The second is by estimating the value of the renewable energy generation either to society or to the utility. Value to society is typically interpreted in terms of the value of the electricity plus climate change mitigation, health impacts, energy security, and other externalities. Value to the utility is understood in terms of avoided generation costs, and the time and location-specific value of electricity supply (Klein, 2012). The third category of approaches sets FIT payments as a simple, fixed-price incentive that offers a purchase price of renewable electricity that is based neither on generation costs nor on the notion of value (Couture et al., 2010). Finally, auction-based mechanisms represent a fourth way to set payment levels. Both India and China are experimenting with this approach, and a few U.S. jurisdictions have expressed interest as well (Couture et al., 2010).

A comparison of FIT policies suggests that those that are most effective in meeting deployment objectives have designed their FIT payments to cover the RE project cost, plus an estimated profit (Mendonça, 2012a). This effectiveness arises from the fact that developers are reluctant to invest unless they are relatively sure that the revenue streams generated from overall electricity sales are adequate to cover costs and ensure a return (Deutsche Bank, 2009). If maximizing deployment is the primary objective, the tariffs can be set aggressively. If a further objective is to limit policy costs, FIT policymakers may want to establish payment levels targeting only the most cost-effective technologies, or limit deployment to areas with the best combination of attributes (e.g. resources, proximity to transmission). Whether payments are set aggressively or more conservatively, policymakers can cast the net wider to capture a greater spectrum of RE projects by designing tariffs for a broader variety of technologies, project sizes, and geographic locations (Mendonça, 2012a).

Another main FIT payment design choice is whether the FIT payment depends on the market price of electricity. These two different policy options are often characterized as fixed-price or premium-price policy designs (Held & Ragwitz, 2006; Klein et al., 2007). In a fixed-price FIT payment, the total per-kWh payment is independent of the market price and constant over a fixed period. By offering reliable, long-term revenue streams, this fixed approach creates stable investment conditions, which can lead to lower project financing costs (Deutsche Bank, 2009; Fouquet & Johansson, 2008). With the premium-price FIT payment option, the total payment is determined by adding a premium tariff to the spot market price of electricity. For this approach, the premium can be designed to approximate the avoided externalities of RE generation, or so that the total payment approximates the RE generation cost. Most countries with FIT policies choose the fixed-price approach, but more are beginning to offer both options (Klein, 2008). Premium-price FIT payments can be designed to be either constant (as fixed or predetermined), or sliding (where the premium varies as a function of the spot market electricity price). Although a constant premium is simpler in design, it risks creating windfall profits for RE developers if spot market prices for electricity increase significantly (Klein, 2008, p. 2; Mendonça, 2012a; Ragwitz et al., 2007). On the other hand, the risk of low electricity prices, and correspondingly low feed in tariffs could drive away potential investors. The following are some of the major elements used in feed in tariff design options.

(a) Annual Allowed Capacity

The overall energy target is divided into annual allowed capacity. This is important to manage and control the quantity of renewable energy fed into the grid and hence ensure smooth supply of energy without impacting grid stability. In addition, exceeding this capacity limit might result in sharp increases in FIT surcharges that could affect end users and taxpayers.

(b) Degression

Degression is a mechanism that decreases the FIT periodically to align it with market changes (increase in technological efficiency and decrease in cost due to economies of scale and learning curve effect).

(c) FIT Term

The FIT term is the period of the purchase contract. This is usually set between 10 and 25 years. FIT terms guarantee a fixed rate when selling electricity from renewable energy sources to help investors and project developers to cover their costs with a reasonable profit margin.

(d) Fixed versus Premium FIT

FITs are provided in two different schemes. FITs are provided with fixed rates throughout the FIT terms regardless of the fluctuating prices of electricity. However, Premium FITs provide a premium profit margin that is added to the price of electricity.

(e) Cap and Floor (for Premium FIT)

Because the premium FIT is a percentage of the electricity price, it is possible to have excessive profits or excessive loss due to fluctuations in the price of electricity. A FIT cap limits the FIT maximum profitability while a FIT floor protects investors by limiting the maximum loss.

(f) FIT Review

FIT policy will have scheduled or unscheduled reviews to update any of the FIT design elements to cope with market changes.

1.6 Feed in Tariff Business Model

FIT is an innovative business model for trading renewable energy. As shown in Figure 1-2 below, renewable energy producers[2] can either sell electricity to the distributing system operators (DSO) or direct transmission system operators (TSO) in cases of large installations. Because the supply company (may be referred to as the electricity utility) buys the RES-e at the expense of FIT, at a rate normally more expensive than the conventional electricity price, the utility sells this electricity to consumers after adding the FIT surcharge.

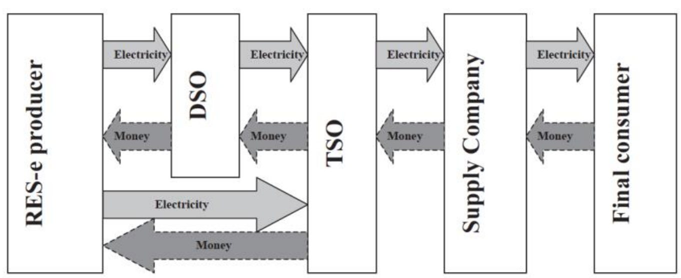


Figure 1-2: General business of model of FIT policy
Source: (Mendonca et al., 2009)

[2] Sometimes indicated as renewable energy source of electricity, RES-e.

1.7 Renewable Energy Economics for Feed in tariff Policy

1.7.1 Experience Curve

Learning curves are phenomena first observed by Theodore Write in airplane manufacturing. He found that the manufacturing time and marginal labour cost reduced over time in a direct relationship with the cumulative production capacity (Wright, 1937). Experience curves, on the other hand, generalizes the labour productivity learning curve to include all the cost necessary to research, develop, produce, and market a given product.

The general experience curve effect is expressed using the following formula:

$$P(t) = P(0) * \left[\frac{q(t)}{q(0)}\right]^{-b}$$

Where

P (t): Average price of product at time, *t*

P (0): Initial price

q (T): Cumulative production quantity at a time, *t*

B: Learning Coefficient

The learning coefficient b is defined with the Progress Ratio, PR, which is observed from the series of product costs, usually between 75 and 85%. Moreover, b can be calculated by the following formula

$$b = \frac{\log(PR)}{\log(2)}$$

$$PR = 2^{-a}$$

$$LR = 1 - PR$$

Where LR is referred to the learning rate. LR determines the reduction in unit cost. Learning curves, however, are expressed in the Progress Ratio. Progress Ratio, or PR, is equal to 1 – LR, so if a certain product has an LR of 20% would be described as having an 80% progress ratio or learning curve of 80%. Learning curves are heavily used to estimate renewable energy future costs. Although it is recommended to use the learning-curve estimation methods of mass production (Chase, Jacobs, & Aquilano, 2006), they have been widely used in major climate change and stability reports by the Agency for International Energy, AIE (Wene, 2000), the Intergovernmental Panel on Climate

Change (IPCC) (Susan, 2007), and the Stern Review (Stern, 2007). In the Japanese context, experience curves have been used by the Ministry of Economy Trade and Industry (METI), and the Wild World Foundation (WWF Japan, 2013a). Due to the stochastic nature of cost and cumulative capacities, it is recommended; however, to complement learning curve estimation with bottom-up models as well as expert insights (Nemet, 2009). Differentiating between global and local learning curves is also essential (Shum, 2013; Van Benthem & Gillingham, 2008). Advanced forms of experience curves were discussed in (A De La Tour, Glachant, & Ménière, 2013; Arnaud De La Tour, Glachant, & Ménière, 2013; Wiesenthal et al., 2012). Recent learning curves of selected renewable energy technologies developed by (WWF Japan, 2013b) are shown in Figure 1-3.

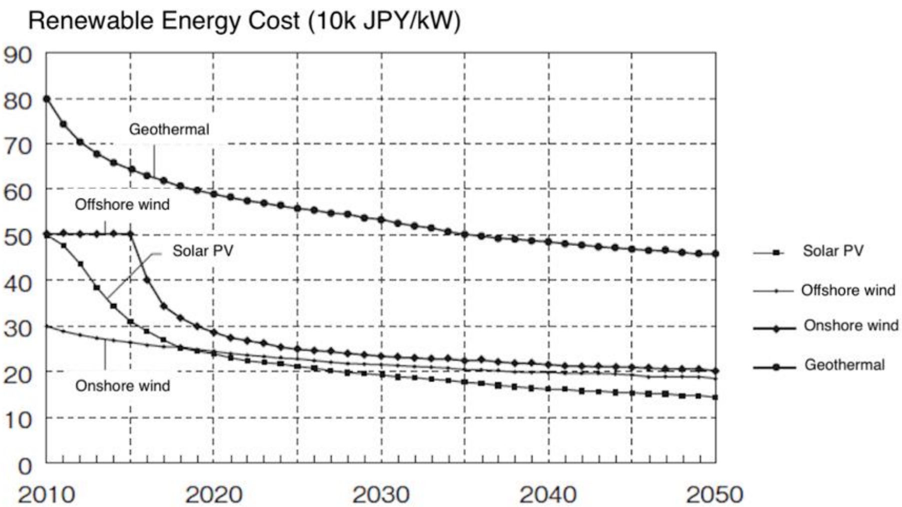


Figure 1-3: Experience curve for selected renewable energy sources in Japan
Source: (WWF Japan, 2013b) adapted from METI data.

1.7.2 Experience Curve for Solar PV

1.7.2.1 The Importance of Studying the Behaviour of PV Markets

Every PV market has it is own specific renewable energy policy and environmental variables. Therefore, it is quite obvious that experiences from other countries cannot be applied directly. However, the accumulation of lessons learned creates a great knowledge asset for policymakers to optimize their decisions and prevent their policies from avoidable, expensive mistakes. To illustrate how challenging the PV market is, this research will provide two case studies. The major benefit of these two case studies is not only to learn from previous mistakes but also to understand the behaviour of policy makers and developers *as a system*. The System Dynamics approach will be used for this behavioural analysis, which will give us some significant criteria for the “what-if” scenarios we are about to develop, and to test the Japanese PV FIT policy against.

There are three principal reasons why the PV learning curve should be studied. First, is that PV is an appealing case where LR have been used to justify public support for these technologies (Nemet, 2009). Second, sales for PV have been growing rapidly at greater than 30% per year, so subsidies to promote PV now involve the substantial allocation of public funds (in the order of billions). Technically, the costs for PV have been dynamic over multiple decades with strong trends of cost reduction over time. Third, PV technology exhibited significant improvements in a single generation. This is unlike the overlapping curves observed in other technologies with a novel architecture such as semiconductors.

1.7.3 Experience Curve for Solar PV Related Technologies

The recent changes in the cost of photovoltaic technology have gained growing attention from key stakeholders, yet it remains challenging to obtain a coherent picture of changes in the PV global value chain that could assist in the forecast of cost patterns. This is for several reasons, which include rapid pattern of price and cost changes, complexity of the PV supply chain (which involve panels makers, balancing of systems manufacturers (BOS), and power plant developers and operators), in addition to the choice of distribution channels (Bazilian, Onyeji, Liebreich, MacGill, & Chase, 2013).

Over the last three decades, PV technologies have faced various technological challenges including performance limitations of BOS components, scaling up manufacturing, shortages of supply and raw materials, and substantial upfront investment costs (Bazilian et al., 2013). For this reason, many scholars have recalculated the experience curve for these technologies to monitor and estimate the cost development. Tsuchiya calculated the experience curve in Japan in 1989. He identified the experience curve for PV used for generation of electricity[3] to be 20–22%. He suggested that the break-even point (BEP)[4] would be achieved by installing an accumulative capacity of 50 GW of PV. Alternatively, at a steeper experience curve, BEP could be achieved at a lower cumulative capacity (Tsuchiya, 1992). However, the 50GW target identified by Tsuchiya was adopted as the NEDO capacity goal by 2050, in the PV Roadmap 2030 and 2030+ reports for the PV industry (NEDO, 2009).

[3] To be differentiated from PV for portable devices popular in the 80's.
[4] BEP refers to the point where PV starts to be competitive.

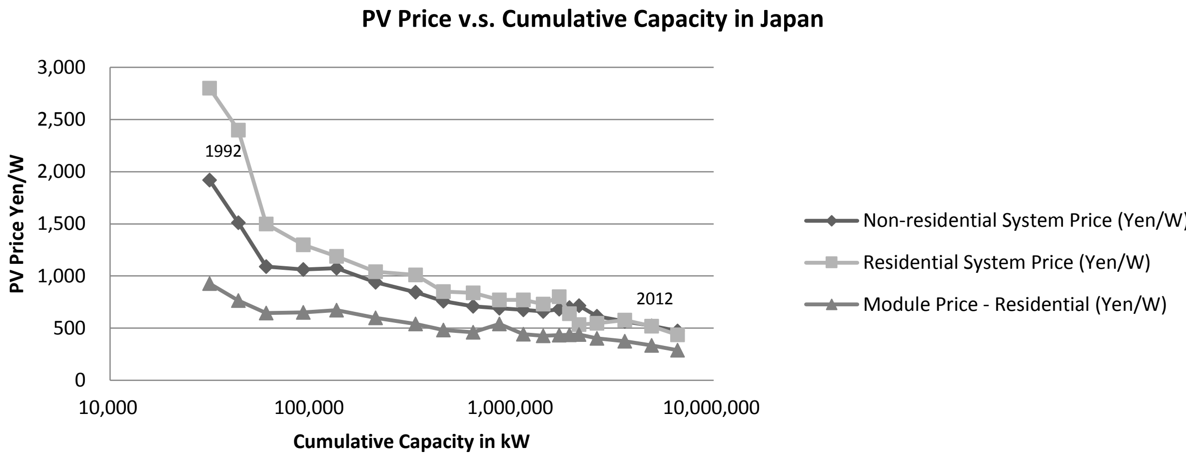


Figure 1-4: PV Module and System Prices against PV Cumulative Capacity in Japan

Source: (IEA, 2012)

In addition to the Tsuchiya work computing the learning rate for PV in Japan, (Kenji Asano, 2010) analysed the learning rates for PV components, namely the installation costs of PV modules, inverters, and other components (mounts, cabling, etc.).

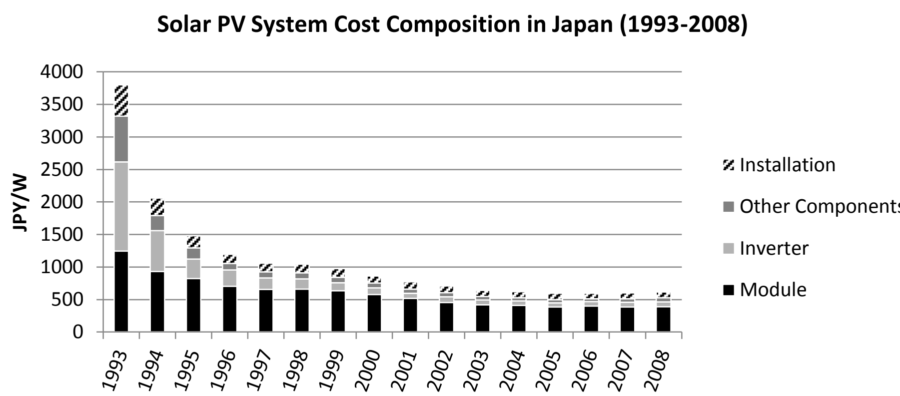


Figure 1-5: PV System Cost Composition 1993–2008

Source: (Kenji Asano, 2010)

Table 1-3: Bottom-up approach for identifying the learning curve for PV projects in Japan

	Modules	Inverter	Other components	Installation
Short-term	16%	25%	20%	12%
Long term	13%	20%	16%	11%

Source: (Kenji Asano, 2010)

As a price-based policy, the feed in tariff value is primarily dependent on the learning curve to project the desired quantities. However, an inaccurate learning curve can give quantitative results that are off target (Menanteau et al., 2003). This might lead to over-budgeting the support policy on the order of billions, and perhaps even trillions of dollars. For example, the debate over subsidies amounting to a few billions in the 2007 Independent and Security Act in the US EIA suggest that programs involving more than hundreds of billions of dollars will be subject to scrutiny. Hence, these cost-projection-based decisions are critical, and mistakes are substantially expensive when they depend on heuristics that mark large uncertainties. The possible consequences of misleading policy design might include continuation of existing programs, early termination, changes in subsidy levels, and (or) supplementing subsidies (Nemet, 2009).

Misestimating of the experience curves occurs due to uncertainties that usually are not considered within the estimation elements. While (Wene, 2000) has emphasized the caveats of using learning curves as "slight changes in progress ratios will improve learning investment considerably", (Neij, 2008) does not recommend it exclusively, but as one of the multiple methods. In fact, PV experience curves do not justify government programs because they conflate multiple effects and ignore probability concerns (Borenstein, 2008).

Back in 1980, (Krawiec, Thornton, & Edesess, 1980) clearly explained some "serious problems" with using experience curves for cost projections. First, the price might exhibit an increase or fluctuate, as in the case of photovoltaics. Long-run costs could increase due to rising input prices, to government regulations requiring higher costs production methods, or to firms adopting new production methods that result in higher production costs. Second, cost changes and technological progress must not be separated, and relying only on cost reductions correlated with falling prices, is not sufficient. Third, the sources of cost reduction must be identified, as there is "no way other evaluate whether cost reduction sources and their impact on costs can be expected to apply to the production of solar technologies". Cost projection without identifying the major sources of reduction might be arbitrary or misleading.

(Imanaka, 2010) has summarized the sources of cost reduction in renewable energy technologies (Table 4).

Table 1-4: Sources of Cost Reduction Identified

Motivations for technological change	Research and Development	The process of knowledge acquisition or development through research
	LBD or Learning by Doing	The process of reducing cost through manufacturing experience

	LBU or Learning by Using	The method of improving the technology through using it
	Spillovers	The process of branching new nascent technologies
Characteristics of the related technologies	Economies of Scale	Cost reduction due to mass production
	Technological Enlargement	Cost reduction through the progression of R&D

Source: (Imanaka 2010)

1.7.4 Levelized Cost of Electricity

Recently there has been some confusion about the economics of PV that came from policy makers misunderstanding the comparative metrics used for evaluating PV costs, particularly for highly used metrics like price per watt (peak) cost of modules (usually expressed as USD/W, and Watt peak Wp), the levelized cost of electricity or LCOE (expressed as USD/kWh), and the concept of grid parity (Bazilian et al., 2013). Each of these metrics is used with a broad range of different assumptions (that consider economic, technological and policy aspects) leading to variations in their results. The use of these metrics differs considerably according to the targeted audience and purpose. For example, the price per watt metric used for solar modules cost is known for its simplicity, as long as data is available. However, it has some disadvantages, for example, it cannot be directly translated into full-system cost, or it averages the dispersed range of different technology costs. In addition, the price per watt can be misleading when it does not explicitly inform whether it is used for manufacturers cost or wholesale price (Bazilian et al., 2013).

Among all energy-generation-project evaluation metrics used (e.g. IRR, ROI), the LCOE is the most widely used by policymakers for analysis of long-term technological competitiveness. LCOE is defined by the International Energy Agency (IAE, 2010) or by the National Renewable Energy Laboratory in the United States (NREL, 2015). The LCOE provides analysis using the project revenues and costs over the lifetime of the generation facility; hence, can be regarded as more accurate when compared with the price per watt metric. The generation values of LCOE might be calculated using annual averages or actual data of energy generation. The LCOE calculation results can provide details pertaining to the performance of the power generation facility, in the kWh generation data. These, in turn, reflect other factors like solar insolation, aging and degradation losses, and the effect of system maintenance (Bazilian et al., 2013; NREL, 2015; Ueckerdt, Hirth, Luderer, & Edenhofer, 2013). However, the LCOE has many disadvantages, primarily concerning the lack of explicit description of the assumptions used in the calculation. Branker et al. indicated the LCOE “is deceptively straight-forward and there is a lack of clarity of reporting assumptions, justifications showing understanding of assumptions and degree of completeness which produces such widely varying results" (Branker, Pathak, & Pearce, 2011). (Namovicz, 2013) indicated that LCOE is "of limited usefulness in the analysis of conventional utility systems, this approach is not generally appropriate when considering unconventional resources like wind and solar". He explains LCOE should not be used to compare with other generation options unless the compared options have similar generation profiles and system values.

In the literature, there are significant variations in the assumptions on which the LCOE evaluation is built. For example, project lifetime is one of the inputs used in the LCOE calculation that aims to determine the duration of the power plant service life. While the PV modules are currently warranted for 25 years or more (Zweibel, 2010), research has shown that 40 years of an operational lifetime has been demonstrated and that 50 years lifetime is achievable when using the crystalline silicon efficiency levels (existing in 2010) (Frankl & Nowak, 2010). Moreover, the operation and maintenance costs for a large-scale PV power plant can vary substantially between 10 and 30 USD/kWh/year (Darling, You, Veselka, & Velosa, 2011; Timilsina, Kurdgelashvili, & Narbel, 2012).

It has been suggested that for LCOE to produce better outcomes, input parameter distributions instead of single numbers should be used. This can result in an LCOE distribution, or a sensitivity analysis, rather than a single value, which implies the uncertainty range and confidence bounds of the LCOE calculation (Darling et al., 2011). In fact, there are more robust metrics than the LCOE. However, the LOCE has become dominant in energy evaluation studies despite these disadvantages (Bazilian & Roques, 2008).

Another important aspect the LCOE fails to address is the value of renewables when its electricity is not subsidized but traded in the wholesale market based on the priority dispatch scheme or merit order. In this case, the value of renewable energy is not fixed (like in the case of a feed in tariff), rather it will be relative to market demand, and therefore, based on the reformed markets. The value of renewable energy increases when its supply profile somehow matches the demand profile and decreases otherwise (Borenstein, 2008; Hirth, 2013; Hirth, Ueckerdt, & Edenhofer, 2012; Joskow, 2011). The LCOE and grid parity are commonly used by government policy makers and require various assumptions. These assumptions include the geographic locations of the production facilities under study, their financial returns, and capital cost requirements, all of which could be incorporated into a single estimate. Instead, the calculation results should be produced using sensitivity analysis in addition to the system boundaries and constraints considered (Bazilian et al., 2013).

1.7.5 Price per Watt

Between 2004 and 2008, the solar PV price was relatively stable (~ 3.5 to 4 USD/W) despite technological improvement and continuous innovation that will force the price down even more. This has been mainly due to the significant development in Germany and Spain, and to policy incentives that helped the project installers to procure the modules at this price. In addition, there was a shortage of the polysilicon stock that kept the modules prices relatively high. Because Spain had a significant share of the global demand, the sudden discontinuation of the Spanish feed in tariff system in September 2008 resulted in accumulation of polysilicon and modules (by 32%) and encouraged manufacturers to sell their modules at half price (from 4 USD/W in 2008 to 2 USD/W in 2009) to continue operating in the market (Wesoff, 2012).

Aside from the module price, the system costs have also fallen steadily since 2004 due to the decline of installation and maintenance costs (Arvizu, Balaya, et al., 2011) and the BOS costs (RMI, 2010), in addition to the cost of capital due to improved understanding of PV project risks and levels of return (IAE, 2010; WEF, 2011). After 2010, solar development in China had a tremendous effect on the global supply of PV capacity and hence induced a dramatic drop in polysilicon and PV prices due to excess production driven by strong Chinese government incentives (Bayaliyev, Kalloz, & Robinson, 2011; History et al., 2013; H. L. Li et al., 2013; Tomoo & others, 2012). The boom in the global export of Chinese modules was considered "dumping" in cases in the European Union (Evenett, 2013), United States (Bradsher & Wald, 2012; Clark, 2013), and Canada (Beetz, 2015). This violates international trade laws set by World Trade Organization, and hence anti-dumping measures have been taken on Chinese PV manufacturers. A similar such case of anti-dumping was raised in India. However, it was rejected shortly due to concerns related to international trade (Chadha, 2014; Kumar & Singh, 2014).

In late 2011, the prices of crystalline silicon c-Si PV modules had declined to 1 USD/W and the reduction of installation cost reached 1 USD/W. This was considered a benchmark making grid parity possible in many countries (Breyer & Gerlach, 2013; Lushetsky, 2010). Such rapid cost adjustment was unexpected by many policymakers. Despite these reductions, policymakers still thought that unsubsidized PV was still far more costly than conventional energy technologies, and, therefore, that high tariffs were needed (Asplund, 2008; Edenhofer et al., 2011; IAE, 2010; Singh & Singh, 2010; Yang, 2010). Whereas one researcher estimated the LCOE of PV to be 0.49 USD/kWh (Yang, 2010), another group of researchers found it to be 0.19 USD/kWh (Timilsina et al., 2012). This was in part due to the use of old numbers that were widely spread among policymakers and investors. In addition, it was found that the photovoltaic costs being compared with nuclear energy or fossil fuel energy costs were not equivalent.

1.7.6 Grid Parity

There are many definitions of grid parity. The PV Parity project is a European collaboration project that defines grid parity as the situation in which PV energy becomes competitive with other technologies (PV Parity, 2013). In other cases, it is more explicitly defined as the achievement a retail price of 1 USD/W for PV modules, as well as another 1 USD/W for balance of the system (BOS) (Sinke, 2009; J. Song et al., 2010; Joonki Song et al., 2009). In general, it was suggested that once grid parity was achieved, renewable energy would be sustainable without subsidies (Yang, 2010) and so it became a policy goal. The concept of grid parity has been falsified for two major reasons. The first is due to the calculation complexity of renewable energy electricity (for example using the LCOE metric). The complexity arises from the components included in the calculations. The second reason is related to the value of the renewable energy over the long term. The point in time where the renewable energy LCOE can be lower than the retail price can be very persuasive. However, when with a higher share of renewable energy penetration, the value of the electricity will drop significantly, to a level that cannot generate sufficient and sustainable revenues for their operators.

(Yang, 2010) discussed two cases where the technologies have achieved lower energy cost than average retail price, and even lower than policy target price, yet those technologies have not prevailed or diffused widely in the market. For example, solar water heaters (SWH), particularly in Hawaii, have an electricity saving cost of about 0.12USD/kWh (US Energy, 2015), which is lower than the price of Hawaiian retail electricity (0.298 USD/kWh) and of the average retail price of electricity on the US mainland (0.129 USD/kWh) (EIA, 2015b). However, many early estimates found solar water heaters in only 1% of households in the United States (Davidson, 2005). By the end of 2012, this figure had increased to 6.7% in the United States and Canada (Mauthner & Weiss, 2014). This conclusion indicates that the achievement of grid parity by itself is not sufficient to achieve the desired diffusion of the technology after stopping supports for renewable energy. (Yang, 2010) explains this is using the “crossing the chasm” concept of Geoffrey Moore (Moore, 2002). The concept suggests that visionaries usually are early adopters of technologies they are not familiar with, due to the excitement of novelty, while pragmatists are mainstream consumers who carefully examine the proven benefits before making their decisions. Considering the SWH example, it seems that achieving grid parity is not actually the main motivation for mainstream consumers. Using an SWH includes a number of inconvenient steps: shopping and procurement, installation, operation and maintenance of the system. Rather it is a convenience, as well as environmental and cost effectiveness benefits, that are needed to cross the chasm. Thus, "the vision for near term grid parity seems to be based on both unrealistic optimism regarding demand growth and unwarranted assumptions regarding the progress ratio of associated costs" (Yang, 2010).

The assumptions are unwarranted because the cost curve of the components has not been well studied. Some studies show that the inverter cost curve is declining at a much slower pace than that of the PV modules. (Schaeffer et al., 2004) found that inverters at the time had a learning ratio of 91 to 96%, which means that inverter cost declined 4–9% percent with each doubling of cumulative volume. This study, however, contradicts other results (Kenji Asano, 2010). (Kenji Asano, 2010) conducted a learning curve analysis of PV and non-PV elements within the PV system, with data from 1993 to 2008. He concluded that, whereas PV inverters had much lower learning ratios of 75–80% (implying expected reduction of inverter cost by 20 to 25% with each doubling of cumulative capacity), PV modules had reduction rates of 13 to 16%. Yet when applying the proposition (Yang, 2010) to the Japanese market, it held true, given the increasing costs of land and grid connection.

Despite the extensive research in which the inefficiencies of the grid parity metric are discussed, many leading scholars and research institutes still used it as means of persuading the public about the optimistic future of the solar and wind development in local economies. Energy evaluation studies in Japan are no exception. Studies typically express an expectation for the achievement of solar grid parity in Japan in 2020 and between 2017 and 2018 of in the case of hybrid integration with other technologies and energy storage capabilities (Richardson, 2015).

1.7.7 The Value of Renewable Energy

One of the metrics used to evaluate and compare alternative energy generation technologies is the Levelized Cost of Electricity (LCOE). According to the MIT report entitled "The Future of Solar Energy", the LCOE is defined as "the charge per kWh that implies the same discounted present value as the stream of costs" or "the minimum price a generator would have to receive for every kWh of electricity output in order to recover the costs of producing this power, including the minimum profit required on the generator's investment" (MIT, 2015, p. 104). One of the LCOE's components is the capital cost (cost of capital), which can be assumed to be the weighted average nominal cost of debt and equity capital (mostly commonly referred to as Weighted Average Cost of Capital: WACC; see (Brealey, 2012) Chapter 19, for details about the WACC). One limitation of the LCOE is that it regards all the kWh produced at a generation facility as the same, whereas the cost should vary according to the time of generation. This is because the cost increases when meeting electricity demand during peak hours (MIT, 2015, p. 104). For this reason, electricity generated from renewable energy is called, “time heterogeneous good” (Hirth, 2013). This is especially valid when renewable energy power plants are no longer supported by subsidy schemes. In such case, the market value of electricity from renewable energy is defined as “the market value of variable renewable energy VRE [is] the revenue that generators can earn without income from subsidies” (Joskow, 2011). VRE is affected by three constraints: variability of supply (profile costs), the uncertainty of future supply (balancing costs), and geographic dependence (grid-related costs) (Hirth, 2013; Joskow, 2011). It has been found that among the costs, the profile costs determined by the variability of supply constitutes the largest portion of all costs (Hirth et al., 2012).

Solar facilities have relatively long life and low operating and maintenance cost (Dunlop, Halton, Ossenbrink, & others, 2005; NREL, 2008). While module warranties last for 25 years or more, annual degradation rates are usually assumed to be 1%. The NREL reported that actual module degradation (especially those manufactured after the year 2000) appear to be between 0.36% to 0.87% per year, depending on the technology (Jordan & Kurtz, 2013). Some argued however that the operational life of a module cannot be known unless the modules are extensively tested (accelerated life assessment testing is usually used to estimate the lifetime of a solar module) (Czanderna & Jorgensen, 1999). This argument is supported by the fact that some solar modules have been reported as functioning even 60 years after their manufacture date (Maehlum, 2014). Kyocera modules installed in 1991 were also reported working reliably after 25 years (Kyocera, 2013). However, as warranties suggest, the minimum guaranteed performance of modules usually drops to less than 80% after the first 25 to 30 years. The recent NREL report about solar module degradation stated that, although the degradation pattern of solar modules is relatively constant and linear within the first 30 years, it becomes nonlinear after that and might result in unpredictable performance levels (Jordan & Kurtz, 2013). (Drury, Denholm, & Margolis, 2011) developed a financial model that considers the operational lifetime of a solar module to be 100 years. They found that the LCOE price could be as low as one cent per kWh. However, even with the common LCOE assumptions of 25 or 30 years, the LCOE has dropped significantly to slightly to less than 0.04 USD/kWh (Brown, 2015). The Lazard report indicated that the solar LCOE, in general, fell 20% between 2013 and 2014, and about 80% since 2010 (Lazard, 2014).

1.8 Criticism of Feed in Tariff Policy

Many aspects of the FIT policy have been generally criticized. This section explores some of the arguments that are common in the literature and discusses the Japanese perspective. First, the policy is considered too expensive when compared with other policy alternatives implemented. Critics in Japan justified their concerns as they were cautious about repeating the boom and bust experiences that took place in Spain, Germany, the Czech Republic, and Italy, and which were followed by government interference that caused catastrophic impacts to the local industries and to RE investment (H. Asano & Goto, 2013; K. Asano, 2012; Clover, Enkhardt, Gifford, & Roselund, 2015). However, scholars and policymakers, and mostly renewable energy enthusiasts, defend their position claiming that incorporating advanced features like continuous reviews and market price monitoring could help make the feed in tariff policy more cost efficient (Couture et al., 2010; Deutsche Bank, 2009, 2011; Jacobs, 2010; JREF, 2012a; Klein, 2012; Kreycik, Couture, & Cory, 2011). Second, feed in tariff incurs substantive surcharges on low-income electricity consumers who actually could not afford to install wind or solar systems. However, this segment of consumers also bears the high cost of non-financial effects of pollution, and negative environmental impacts of fossil fuel power generation.

The FIT is also criticized for the fact that it dictates inflexible pricing by setting a fixed rate for the tariffs rather than allowing the market to set a price (Deutsche Bank, 2009). This is claimed to create instability and inability to react to dynamic market conditions. However, feed in tariff policies incorporate the tariff degression mechanism, which is used to adjust the tariff and adapt to market dynamics (Couture et al., 2010; Grau, 2014b; Klein, 2012).

Avoiding well-established nuclear energy production and investing in high-cost renewable energy resulted in rising costs for households, and created substantial losses for utilities and energy intensive industries. These eventually weakened the economy and overall industrial competitiveness. Consequently, the policy has countered these critics by offering exemptions to energy intensive industries because they have a vital role in supporting the economy.

The FIT is a subsidy that benefits those able to install solar systems, who are usually high-income individuals who can afford to purchase such systems. However, the feed in tariff budget is paid by all electricity consumers including low-income individuals who cannot afford to purchase rooftop solar systems. This raised a heated debate about the fairness of the feed in tariff policy, as it appears to be designed only for the wealthy. (Ebinger et al., 2014) claims that "it is far too soon to discourse about the effectiveness of the FIT in Japan and its long term results will not become evident for years". This claim is based on the fact that although the FIT program tripled the independent power producers (IPP) in Japan, they still represent less than 3% of the country's overall power production (Ebinger et al., 2014; McNeill, 2013).

The policy is also considered ineffective and incompatible with other existing policies used to promote renewable energy, and to pick specific technology winners from losers. In this regard, matured technologies fare well when compared with solar photovoltaic, for example, because the mature technologies have lower costs and hence lower policy budgets. On the other hand, it is prudent to support a broad range of renewable energy technologies based on their maturity level and the cost of the electricity they generate. Moreover, the pricing of the feed in tariff is intentionally designed to drive innovation, especially for technologies with high potentials like solar photovoltaic. Regarding compatibility with other policies like the renewable portfolio standard (RPS) or renewable energy certificate, the feed in tariff is assumed to share the same objectives of increasing the renewable energy share and climate mitigation. Moreover, the feed in tariff could be considered a complementing policy for RPS for example, where RPS could be leveraged as a demand pull while the feed in tariff acts as the supply push (Deutsche Bank, 2009).

Because the feed in tariff encourages the public to be independent power producers (IPPs), a burden is passed to transmission operators and utilities to deal with many individuals. It also creates an additional administrative cost for the government to process a large number of applications for small systems as well as introducing a complex payment process for power generators. This comes as a natural cost of scaling up distributed energy generation. The decentralization and public participation in energy generation make the energy system more resilient and have many other invaluable benefits. Another argument against the feed in tariff policy was related to the effect on employment. According to a study developed by (Alvarez, Jara, Juliá, & JIG, 2009) from King Juan Carlos University in Spain, there was a claim that the feed in tariff policy resulted in significant losses according to net job indicators. Another study conducted in Germany stated that, although the FIT succeeded in creating jobs in Germany, these jobs might be lost as soon as the support for renewable energy stopped (Frondel, Ritter, Schmidt, & Vance, 2010a; GPER, 2012).

Nevertheless, the methodology and the use of data in the study cited above have been falsified by many other counter studies. Empirical evidence from Germany shows that the FIT policy created long-term jobs that will be sustained because the global demand for renewable energy is increasing year by year, creating more employment opportunities (BMWi, 2014; Fraunhofer, 2014). The Fraunhofer Institute and the Federal Ministry of Economic Affairs and Energy in Germany are conducting updated reports intended to verify information pertaining to renewable energy. Indeed, because of the success attributed primarily to the feed in tariff, many governments have set national targets for renewable energy following the leading countries in Europe and even increased those targets again within a few years after their initial announcement. The renewable energy in China, India, and many other developing countries shows clear evidence that the demand for renewable energy is increasing. Moreover, the amount of investment in renewable energy has doubled in recent years, which is another strong indication that green jobs will be sustainable (Lewis, 2014).

1.9 Summary

This chapter discussed renewable energy policy literature. It provided an overview of the major academic debates about the rationale behind renewable energy support and shed the light on the importance of considering multi-objective justification for those policies. It introduced the feed in tariff policy and briefly compared it with other dominant policies. It also discussed major aspects concerning its design options and the economic variables within its calculation structure. It finally provided a brief debate pertaining the critics of this policy.

2 Renewable Energy Market Development Under the Feed in Tariff Policy

Overview

In this chapter, the impact of feed in tariff policy on market development in the Japanese market, as well as in the main European markets, is discussed with emphasis on solar PV technology.

2.1 Introduction

The feed in tariff policy amendment in 2012 has had a significant influence on increasing the share of some renewable energy technologies. For example, the METI statistics have shown that the non-residential solar PV capacity introduced within two years after implementation of the policy was almost 6-times as much as all the deployments achieved in the last three decades. This rapid development could take place due to the new policy reforms in the feed in tariff policy that allowed large-scale power plants and adjusted the power plant capacity limits imposed in previous policies, like net metering and the solar feed in tariff for a surplus generation. In addition, the new tariff policy provides a clear commitment to fix the tariff price and therefore reduce the uncertainty and risk of unexpected tariff price changes, or even the suspension or termination of the policy. Table 2-1 and Table 2-2 summarize the incentive policies before FIT enactment in July 2012.

Table 2-1: Summary of PV incentives before FIT enactment

	Net Billing	FIT for surplus power
Enforcement	1994 to Oct. 31, 2009	1 November 2009 to 30 June 2012
Legislation	No Voluntary scheme by utilities	Yes Obligation to utilities
Capacity	Not defined	500 kW limit
Purchase rate	Same as the electricity rate e.g. residential 24 JPY/kWh	For < 10kW 2009: 48 JPY/kWh, 24 JPY/kWh 2010: 48 JPY/kWh, 24 JPY/kWh 2011: 42 JPY/kWh, 40 JPY/kWh
Purchase term	Not defined	10 years
Financial resources	Utilities	All electric consumers

Source: (RTS Corporation, 2012)

Table 2-2: Comparison between pre and post implementation of the FIT policy in Japan

	Amount deployed as of without feed in tariff (end of June 2011)	Capacity of facilities that started operation between July 2012 and March 2013	Capacity of facilities that started operation between April 2013 and March 2014
Solar power (residential)	4,700 MW	969 MW	1,307 MW
Solar power (non-residential)	900 MW	704 MW	5,735 MW
Wind	2,600 MW	63 MW	47 MW
Mid to large sized hydraulic (1000 kW or more)	9,400 MW		
Mid to small size hydraulic (less than 1000 kW)	200 MW	2 MW	4 MW
Biomass	2,300 MW	30 MW	147 MW
Geothermal	500 MW	1 MW	
Total	20,600 MW	1,769 MW	7,240 MW

2.2 Feed in Tariff in Japan

The Japanese market for PV energy is one of the most controversial markets in the world. It has been recognized for as No. 1 global player in terms of manufacturing capability, local deployment, and exports for nearly a decade. Surprisingly, this market suddenly slowed down and stagnated due to the absence of serious support. The market share of Japanese manufacturers declined from more than 50% in 2005 to 8% in 2012 (METI, 2012). The new policy announced on 1 July 2012 was expected to change drastically the Japanese PV market, by facilitating utility scale projects more than residential applications (Ogimoto, Kaizuka, Y. Ueda, & Oozeki, 2013). The incentive prior to FIT policy was restricted to home applications and other facilities of less than or equal to 500 kW. The new Japanese FIT, however, removed this restriction to open the market to large installations. With an ambitious plan, the FIT price was set to 42 JPY/kWh, which is the highest value among other renewable energy technologies like wind and biomass. This attracted not only local investors and project developers but also foreign competitors seeking new markets to adjust their financial performance.

In 2008, Prime Minister Yasuo Fukuda presented a plan to achieve a 50% reduction in global emissions by 2050. The Fukuda Vision dramatically changed Japanese attitudes. In response to the Fukuda Vision, the “Action Plan for Achieving a Low-carbon Society” was approved by the cabinet in July 2008, and national targets for cumulative PV were set at 14 GW by 2020 and 53 GW by 2030. As part of this development, METI decided to reintroduce a subsidy for residential PV, which had been terminated in 2005. Despite the withdrawal of the earlier support, the largest PV sector in Japan is still residential, accounting for about 86% of domestic shipments. Under the new framework, METI will subsidize residential systems up to 10 kW, providing 70,000 JPY/kW (774 USD/kW). The new program, which supports both installation and equipment costs, started in January 2009 with a budget of 9 billion JPY (99.5 million USD). A further 20 billion JPY (222 million USD) was appropriated for FY 2009 and tens of thousands of households were expected to be supported.

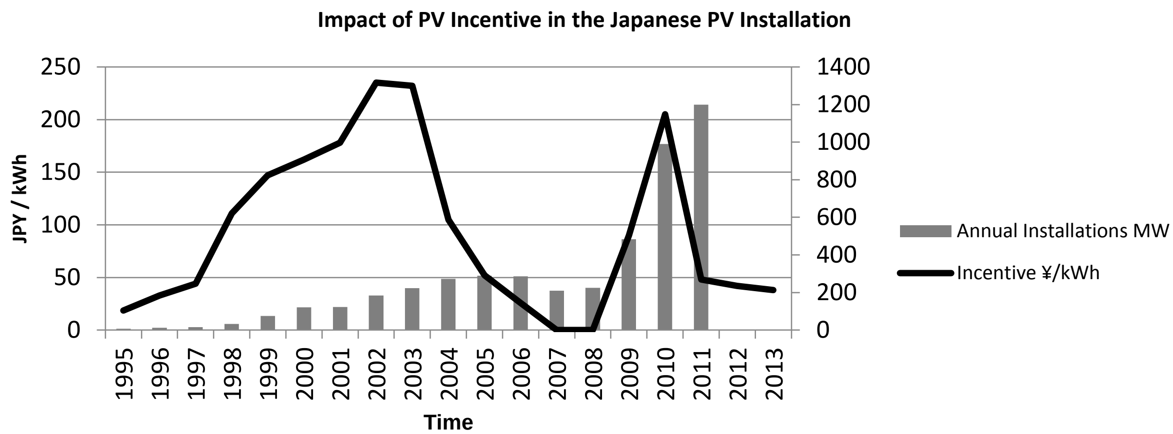


Figure 2-1: Impact of PV incentives on PV market growth in Japan

Note: (1) The government subsidy was stopped by the fiscal year of 2005 and resumed back again in 2007. (2) Solar feed in tariff policy or solar FIT was introduced in 2009 (3) The subsidy support of feed in tariff policy started in July 2012 as a countermeasure to the Fukushima accident in March 2011. Source: (RTS Solar, 2012)

METI also started a new R&D program to develop cells with conversion efficiencies of over 40% and established a 'Study group on low-carbon power supply systems' to identify the challenges of expanding PV, and appropriate responses. The Ministry of the Environment (MoE) has also been accelerating measures in accordance with 'a strategy for becoming a leading environmental nation in the 21st century' (a decision made in June 2007). While continuing support for a 'mega-scale PV power plant', the MoE also started a new residential program. Three local governments received MoE subsidies to introduce housing PV systems, and MoE was also preparing new measures for 2009.Moreover, four ministries (METI and MoE, together with the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Land, Infrastructure and Transport) jointly announced an 'action plan for the dissemination of PV power generation', declaring that the four would join hands on the project. Local governments not only continued subsidy programs for residential PV systems but also started unique programs to support PV power generation. By the end of 2008, such activities were being promoted at the municipality level — and over 300 municipalities continue to provide their subsidy or preferential loan programs for residential PV systems. For example, in the capital, the Tokyo Metropolitan government prepared for a large-scale project to install PV systems on 40,000 houses (totalling 1 GW) from 2009 to 2010. Aichi

Prefecture started a buy-out system for Green Energy Certificates as a method to support PV. Kyoto Prefecture implemented a system for companies to buy credits for residential CO_2 reduction and started a model system to accredit Eco Points for efforts at reduction of energy consumption. In Yokohama City, Kanagawa Prefecture developed an anti-climate change policy and conducted further promotion of PV.

Table 2-3: Feed in tariff policy for solar systems below 10 kW

		2012	2013
Procurement value		42 JPY/kWh	38 JPY/kWh
Installation Cost	System unit cost	466,000 JPY/kW (Jan to Mar 2012)	427,000 JPY/kW(2012 Oct-Dec)
Grant	Government	35,000 JPY/kW	20,000 JPY/kW
	Prefecture	38,000 JPY/kW	34,000 JPY/kW
Running cost	Maintenance cost	1% of installation cost	Similar to previous year
	Labour cost		
IRR		3.2 %	Similar to previous year
Procurement term		10 years	

Source: (METI, 2013)

Table 2-4: Feed in tariff policy for solar systems above 10 kW

		2012	2013
Procurement value		40JPY/kWh	36 JPY/kWh
Installation Cost	System unit cost	325,000 JPY/kW	280,000 JPY/kW
	Land development	1500 JPY/kW	20,000 JPY/kW
	Land rent	150 JPY/m2	34,000 JPY/kW
Running cost	Maintenance cost	1.6% of installation cost	Similar to previous year
	Labour cost		
	Administrative cost	14% of Maintenance cost	Similar to previous year
	Personnel expenses	3,000,000 JPY/Year	Similar to previous year
IRR		6.00%	Similar to previous year
Procurement term		20 years	

Source: (METI, 2013)

This city also utilizes the Green Power Fund to demonstrate community-based new energy resource projects. Electric utilities have also been supporting PV system installations through net billing and buy-back of excess electricity at the retail price, supporting the Green Power Fund for PV deployment in public facilities, and complying with the Renewables Portfolio Standards (RPS). In addition to these measures, utility groups have announced a plan to construct PV power plants with total capacity of 140 MW at 30 locations across Japan by 2020.

2.3 Comparison with Feed in Tariff Systems in Major European Countries

When comparing major FIT systems in the European Union (Germany, Spain, and Italy), it can be seen that the FIT price is quite close to the one set in Japan, however, with variation of program period and PV system classification. The following tables show the feed in tariff structure and pricing scheme for photovoltaic energy projects in the respective countries.

Table 2-5: PV FIT System in Germany 2012

		Feed in tariff (Inc. tax)		Program Period (Years)
Generation Type	Classification	Euro cents	JPY	
Roof installations	0-30 kW	24.3	31.88	20
	30-100 kW	23.23	30.32	
	100-1000 kW	21.98	28.68	
	1000 kW or more	18.33	23.92	
On ground installations	Utility scale	18.76	24.48	

Source: (METI, 2014b)

Table 2-6: PV FIT System in Spain 2012

Generation Type	Classification	Feed in tariff (Inc. tax)		Program Period (Years)
		Euro cents	JPY	
Building Integrated (BIPV)	~20 kW	26.62	34.74	30
	20-200 kW	19.32	25.21	
Ground Mounted	~10 MW	12.17	15.88	

Source: (METI, 2014b)

It can be noted that the structure of the tariff pricing and classification of technologies (or technological topology as referred to by (del Río González, 2008)) qualified for the feed in tariff support varies from country to another. Yet, there is a growing literature which focuses on the convergence the feed in tariff policies among the member states of the European countries to benefit from the cross-border integration of the electric network (see (Jacobs, 2012a) for background about the recent development in policy convergence in EU).

Table 2-7: PV FIT System in Italy 2012

Generation Type	Classification	Feed in tariff (Inc. tax)		Program Period (Years)
		Euro cents	JPY	
Building Integrated (BIPV)	1-3 kW	27.4	35.76	20
	3-20 kW	24.7	32.23	
	20 - 200 kW	23.3	30.41	
	200 - 1000 kW	22.4	29.23	
	1000 - 5000 kW	18.2	23.75	
	5000 kW or more	17.1	22.32	
Ground Mounted	1-3 kW	24	31.23	
	3-20 kW	21.9	28.58	
	20 - 200 kW	20.6	26.88	
	200 - 1000 kW	17.2	22.45	
	1000 - 5000 kW	15.6	20.36	
	5000 kW or more	14.8	19.31	

Source: (METI, 2014b)

2.4 Development of Solar Deployment in Japan

The oil crisis in the 1970s cast its shadow on many economies around the world, the challenge of energy security to the table for discussion among policymakers. At that time in Japan, crude oil from the Middle East represented more than 70% of its energy mix, and the spiking oil prices caused its export-based manufacturing economy to plunge. Although oil prices fell after political stability was restored during the 1980’s, the Japanese government and companies have continued to explore PV energy especially by harnessing its unique position involving the production of semiconductors and electronics. Solar PV development in Japan started after Bell Laboratories (USA) invented solar silicon in 1953. Those developments were focused on niche commercial applications like space applications (satellites and spacecraft), telecommunication applications in remote areas, and off-the-grid lighthouses in the 1960s and 1970s.

The renewable energy policy in Germany was motivated by the desire to phase out nuclear energy and foster economic goals (like creating new clean industries, creating jobs, and stimulating trade and export). By contrast, Japanese policy was motivated by the desires to balance economic, environmental, and energy security goals, and more specifically, using fossil-fuel-free alternative energy sources and technologies (Ebinger et al., 2014). In other words, the renewable energy policy in Japan has not been sensitive to the removal of the nuclear energy choice from its list of essential energy sources, but rather towards limiting imports and reducing dependence on foreign fossil fuels that affect its energy security.

The development of solar PV in Japan has been described in three phases (Kimura & Suzuki, 2006).

Phase 1 (1974–1984) Development of remote and independent solar power systems

The Japanese government launched its first policy for promoting photovoltaic solar energy in response to the oil crisis. The promotion policy (the Sunshine Project) was intended to promote research and development of solar energy applications and to provide a significant share of non-fossil fuel by the year 2000. Its budget was revised and increased substantially after the second oil crisis in 1979, during the Iranian revolution.

Phase 2 (1984–1994) Demonstrating the results of the Sun Shine Project

During this period, many concept projects successfully demonstrated that solar energy was a prudent strategic choice to be explored and invested in. This was considered major progress for the Sunshine Program. Amorphous silicon-based solar panels were exploited in consumer electronics like calculators. However, the market was marginal due to low demand for renewable energy.

Phase 3 (1995–2007) Diffusion of rooftop PV systems

Residential or rooftop solar PV systems increased rapidly in the 3rd phase due to government intervention, which proved a major catalyst for speeding the diffusion process. The government intervention package involved easing rules on installation processes and procedures, standardizing and simplifying grid interconnections, and providing technical guidelines, in addition to subsidies offered to minimize the prohibitive initial cost investment.

During the period between 1985 and 2007, Japanese companies and research institutions filed twice the number of patents filed by their solar technology rivals in the United States and Europe, combined. The cumulative power generation from solar PV facilities doubled 500 times compared with the levels in 1991 (Fairley, 2014). For example, in 1998, the Japanese company Kyocera became the largest producer of solar cells in the world. Kyocera was followed by other Japanese companies that became global leaders in solar panel manufacturing, and Japan had the largest share of solar deployment.

The Japanese renewable energy policies and subsidy program seemed to work exactly as intended. In fact, the plan was aligned with the carbon-emission-reduction targets and climate-change mitigation policies enacted in the Kyoto Protocol in December 1997. The investment in technological innovation over two decades produced massive diffusion of solar PV, and supported local manufacturers in their positions of global leadership. Eventually, this created a better position from which to achieve the national renewable energy and carbon emission reduction targets. However, the nuclear energy trackWas also adopted. Nuclear energy was seen as a stable power supply supporting energy security whereas solar energy was regarded as intermittent and unreliable. Former prime minister Naoto Kan blamed the utilities for such strategic diversion: “The reason is very clear. The electric power companies, the people who wanted to promote nuclear power, opposed [PV]” (Fairley, 2014).

Phase 4 (2007-2012) Policy Failure and Introduction of the FIT policy

Due to the suspension of solar subsidies in Japan in 2005, new solar deployment declined substantially when solar installation was no longer a financially viable business. Consequently, solar PV production by Japanese manufacturers dropped to unprecedented levels, causing Japan to lose its position as market leader in both deployments (2005) and manufacturing (by 2008).

2.5 PV Industry in Japan

Similar to other industries, the PV industry has been and still is, dependent on support policies, and is sensitive to changes that affect it. The suspension of support in 2007 and 2008 drastically affected the growth of PV and shrank the size of the industry. The effect of the high FIT can be clearly seen in the increase in installations between June 2012 and February 2013. One unique aspect of the Japanese PV industry is that the residential sector has been the most active part of the PV segments. This is mainly for two reasons. First, is that obtaining grid-connection permits is quite complex for an applicant with project size greater than 50 kW. This requires connection to the high-voltage grid, which has different procedure and requirements than other applications with size less than 50 kW (BNEF, 2013a). Moreover, because the grid is still controlled by utilities, the utilities are reluctant to give away their share of electricity to solar generators given that large-scale PV might affect the stability of the grid. Another reason behind the better residential PV diffusion is that, unlike large-scale applications, residential PV is not concerned with grid transmission capacity across the prefectures.

Large-scale PV developers seek affordable land for their projects and tend to concentrate in areas with small populations, compared to the main cities. However, the fact that the city has a small population means that the grid capacity is limited to the city demand. What happened over the last two years, since the commencement of the FIT system, is that many applications were submitted to install projects in areas with the affordable land. The supply from these larger PV systems would exceed the city power demand, and even exceed the grid transmission capacity necessary for them to transfer electricity to the utilities in nearby prefectures (BNEF, 2013b).

The Figure 2-2 shows the quantity of electricity generated (kWh) for the technologies supported under the feed in tariff policy. As can be seen, the growth of the wind and solar technology share over time is dominant among other technologies like geothermal and hydropower generation. This in part is due to the application process for obtaining construction permits from METI as well as other entities like the Ministry of Environment. In addition, it is also due to the construction time required for geothermal and hydropower plants, which ranges between 5 and 10 years.

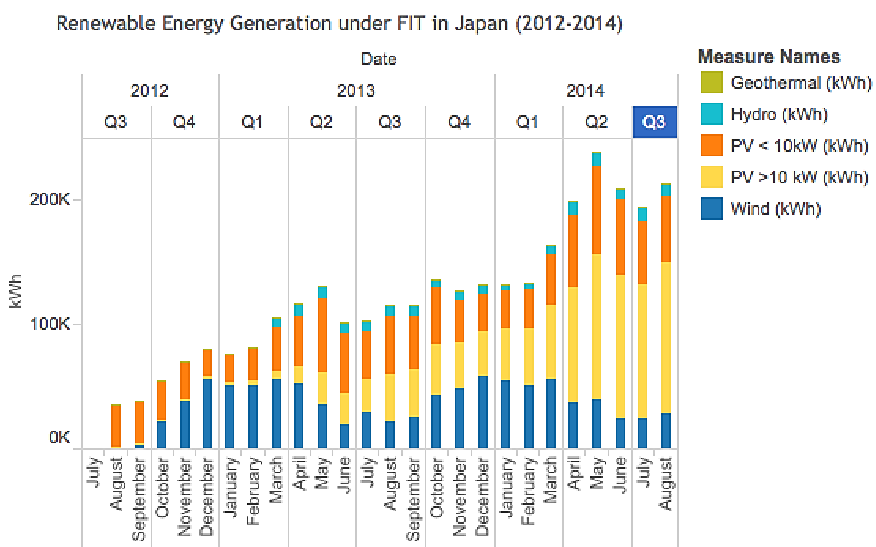


Figure 2-2: Renewable Energy Generation by Energy Source in Japan

Note: (1) The figure shows the generation of renewable energy power plants under the feed in tariff supports since the introduction of the policy in July 2012. (2) The generation of varies of wind technologies to seasonal changes in wind resources availability. Source: Author's drawing with data obtained from METI feed in tariff statistics (METI, 2014b)

The growth of PV deployment in Japan for a 10-year period is illustrated in Figure 2-3. The figure can show the impact of different policies adopted during this period. The quantity of PV systems exported can be attributed to the overseas demand, driven by the renewable energy policies there. The growth from 2012 onward can primarily be attributed to the new feed in tariff policy. It is important to note how the policy created significant local demand on which all manufacturing facilities have focused their shipments. Moreover, because the Japanese solar market was open to the competition of foreign manufacturers, who offered solar modules at roughly half the cost of their Japanese counterparts, Figure 2-3 illustrates the increasing trend of importing solar modules from overseas and the declining volume of local manufacturing. In fact, it became difficult for Japanese companies to sustain competition with foreign players since the majority of them have manufacturing facilities based in China, Thailand, or Malaysia.

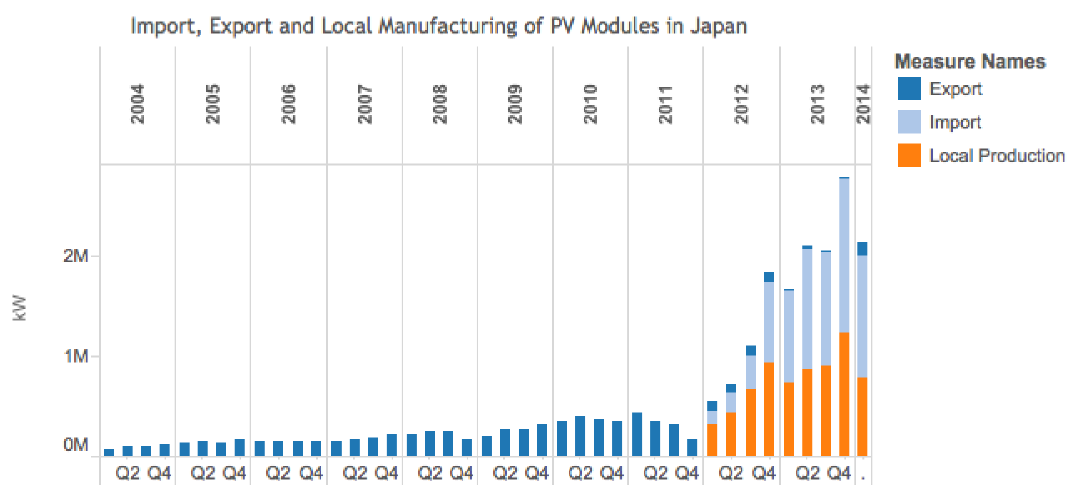


Figure 2-3: Import, export, and local manufacturing in Japan for PV modules

Note: (1) Local production refers to the share of modules manufactured in Japan for local use. (2) The data in this figure does not suggest that locally manufactured modules only started in 2012. The figure was created by the author, data from (JPEA, 2015).

The development of solar technology, however, has faced several challenges, including grid capacity congestion. Figure 2-4 shows a trend in which solar project applications became negative. METI has introduced a regulation about delaying projects, which states that any approved project from METI will be cancelled if it is not developed within 18 months from its approval date. Such delays in construction of approved solar projects are due to the following reasons. Given the declining cost of solar modules, many project developers seek to obtain METI approval and a grid connection permit; then delay construction until the costs of PV modules and equipment decline further. Another reason is that some projects are abandoned. This may be due to the constraints and delays imposed by utility operators for grid connection permits, and to periods when applications are not accepted for any renewable energy project. The development of solar PV under the new feed in tariff policy has also shown the distinct phenomenon that large-scale PV projects started to outpace residential ones. This trend is driven by profitability gains and the guaranteed return on investment, which is much higher in the case of utility-scale PV power plants when compared with the residential rooftop sector. In addition, PV project developers, as well as companies in the telecommunication, real estate, and banking sectors, were actively investing in large-scale PV power plants. Although some companies offered various financing solutions to exploit the aggregation of residential rooftops to mimic utility-scale power plants, the conventional large-scale project remained dominant.

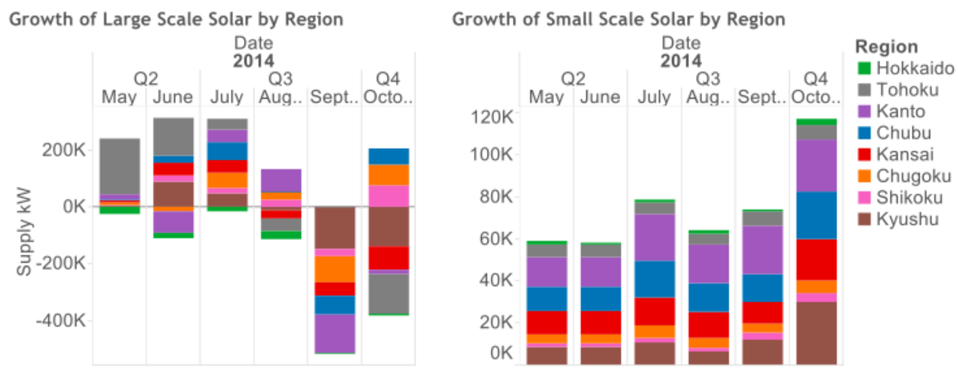


Figure 2-4: PV Applications filed at METI in major regions in Japan

Note: (1) The figure shows PV applications submitted and approved by METI, not necessarily constructed. (2) Applications in negative numbers represent applications rejected by METI. The figure was created by the author, data from (METI, 2014b).

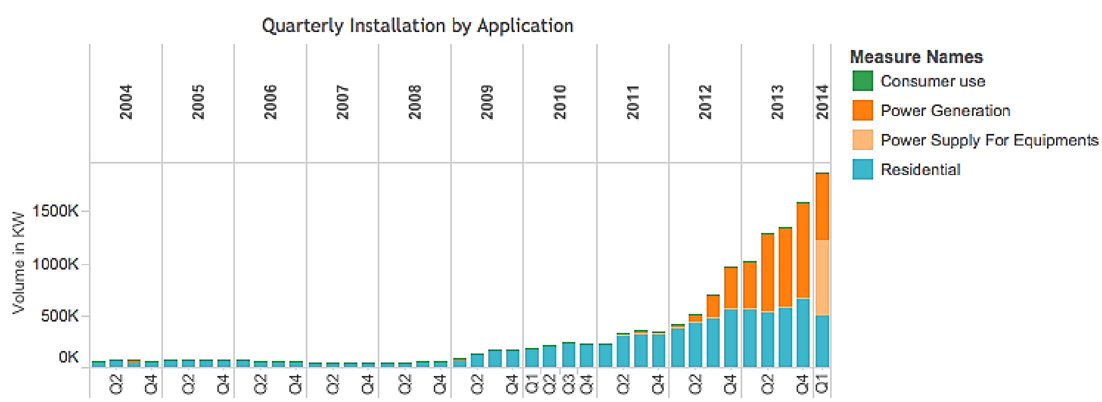


Figure 2-5: Quarterly deployment of PV projects by applications

Source: (JPEA, 2015)

When considering the technologies used in the PV projects, it can be seen that the vast majority of projects used silicon-based PV modules. This is mainly because silicon-based modules have a higher photoelectric conversion rate than thin-film based PV modules. The limited space available on Japanese rooftops and the high price of land (per square meter) in rural areas biased the choice toward more efficient modules.

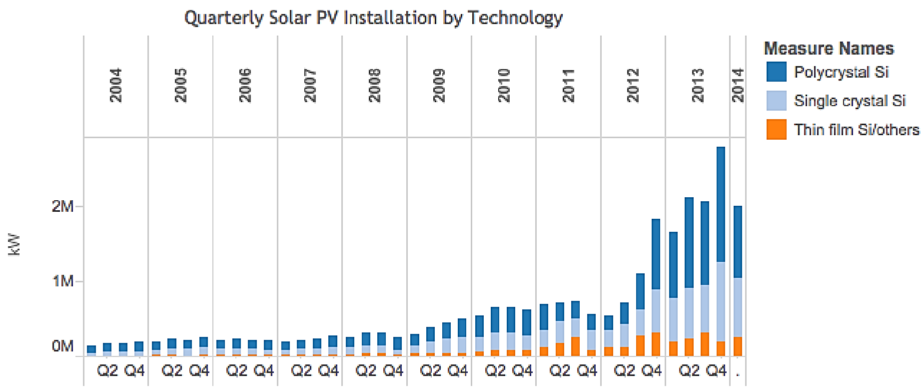


Figure 2-6: Quarterly PV deployments by technology

Source: (JPEA, 2015)

According to the data obtained from the METI related to the feed in tariff statistics for solar PV projects, the distribution of solar PV projects differs depending on the project type. Small scale projects seem to concentrate in major cities where with high population density whereas large scale projects are seen to concentrate in areas remote areas with rich solar irradiation resources. The ease of grid access and cost of appropriate land are major determinants for large-scale project development. This subject will be discussed in more details in chapter six.

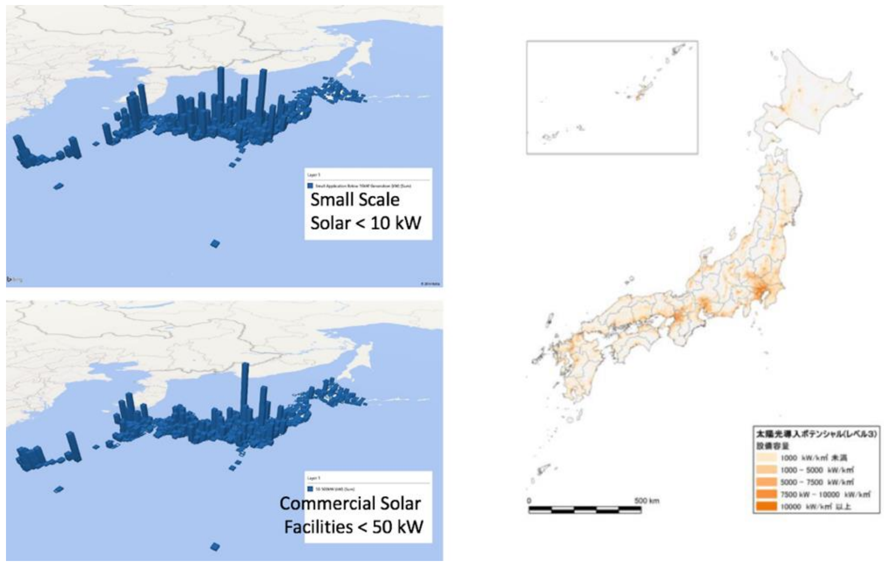


Figure 2-7: Geographic distribution in Japan of small-scale solar PV projects

Source: Maps on the left are Author's drawings with data obtained from Japan feed in tariff statistics, maps on the right are obtained from the Ministry of Environment, Japan, for the geographical zoning assessment of solar energy resources (MoE, 2013).

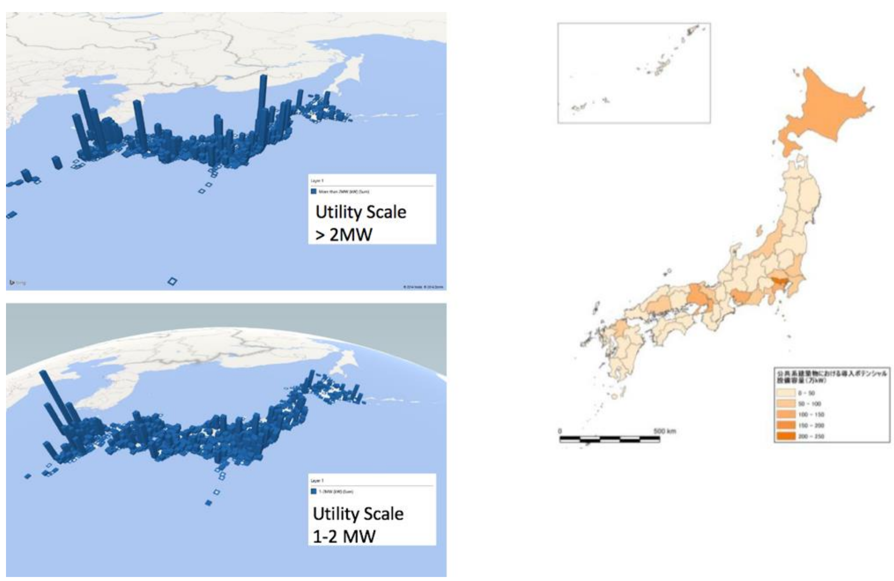


Figure 2-8: Geographic distribution in Japan of small-scale solar PV projects

Source: Maps on the left are Author's drawings with data obtained from Japan feed in tariff statistics, maps on the right are obtained from the Ministry of Environment, Japan, for the geographical zoning assessment of solar energy resources (MoE, 2013).

2.6 Wind Energy Development in Japan

Unlike the case with solar PV, the development of wind energy projects has exhibited limited growth after the introduction of the feed in tariff policy. In fact, the wind energy sector has suffered from stringent regulation and assessments imposed by the Ministry of Environment in Japan. The Japanese Wind Power Association indicated that the wind energy target of 3G by 2010 was not achieved due to the strict policies dictated by the MOE, which regulates wind turbines as skyscrapers (JWPA, 2015; Publicover, 2015). Moreover, the recent reluctance of eclectic utility operators has added further obstacles. They have shown no serious interest in developing the transmission lines needed to exploit the substantial wind resources available in northern Japan.

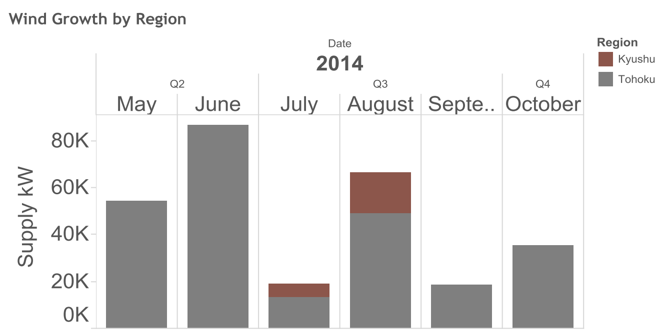


Figure 2-9: Wind energy projects approved by METI between May and October 2014

Note: (1) The figure shows small and large wind applications. (2) The figure shows wind energy projects in Kyushu and Tohoku because the METI approved projects while this period were limited to these two regions. 3) The period between May and October 2014 witnessed the grid connection disputes between developers and utilities in charge of the regions indicated in the figure. Source: (METI, 2014b)

Due to the limited support wind energy development has during the past decades; the growth of wind energy share has been marginal when compared with other major markets.

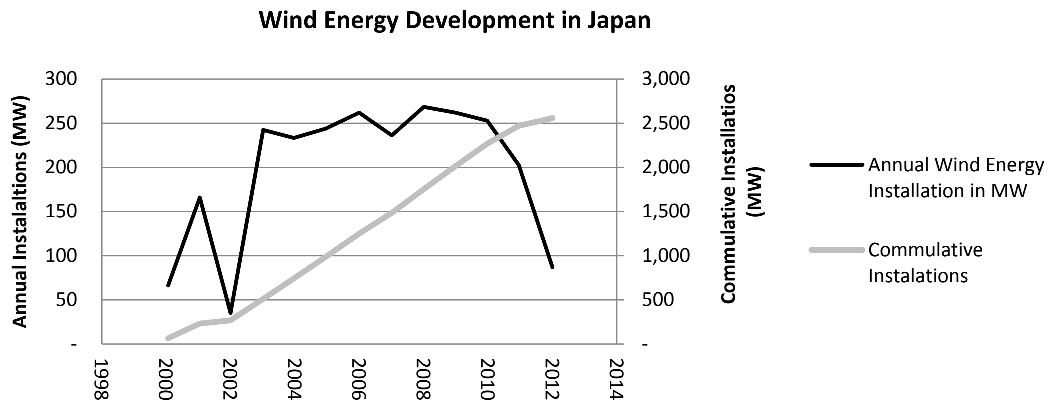


Figure 2-10: Wind Energy Development in Japan

Note: Wind energy projects shrunk significantly after the introduction of the feed in tariff in 2012, due to the requirement for environmental assessments (JWPA, 2015).

The project distribution analysis below shows that wind energy projects have been targeting areas that do not necessarily have the highest wind resource potential. As it will be discussed in later chapter

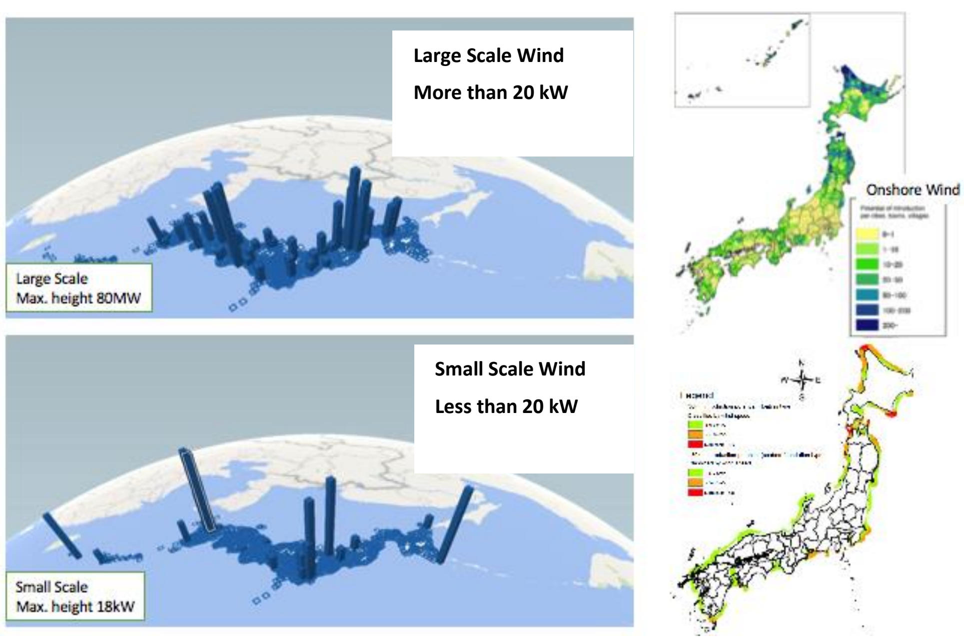


Figure 2-11: Wind energy distribution in Japan

Source: Maps on the left are Author's drawings with data obtained from Japan feed in tariff statistics, maps on the right were obtained from the Ministry of Environment, Japan, for the geographical zoning assessment of wind energy resources (MoE, 2013).

2.7 Case Studies: Feed in Tariff Policies in Major Markets

This section will discuss two case studies that discuss the design evolution, market development and policy challenges faced when introducing the feed in tariff policy in Spain and Germany.

2.7.1 Feed in Tariff Policy in Spain

The Spanish FIT was praised as an excellent and successful mechanism for exceeding the national RE targets ahead of time, as well as significantly reducing carbon emission. Nevertheless, this experience has been also described as “a complete failure” in the sense that it had not the way to monitor and apply appropriate controls in response to market dynamics (de la Hoz, Boix, Martín, Martins, & Graells, 2010). However, this experiment provided a real leap in setting the basic infrastructure and regulatory foundations for PV facilities in different typologies (rooftop, ground mounted, and isolated systems). It has been noted that the PV diffusion success was not merely because of the selection of the particular promotion scheme (i.e. FIT) but instead was due to the FIT design elements. Since the announcement of FIT in Spain, extensive research has explored the effectiveness of this policy in extensive detail (Bechberger, 2006; Bustos, 2004; Dinica, 2003; García & Menéndez, 2006; Lopez, 2000; Meyer, 2007). The PV industry was also a refuge for the Spanish economy during the economic crisis in 2007-2008 because of the quick job creation that accompanied large-scale PV project installations. A summary of the Royal Decrees is mentioned in Table 2-8.

Table 2-8: Summary of PV Subsidy and FIT regulations in Spain

Year	Royal Decree	Notes
1980	82/80 Law for Energy Conservation*	Approval of feed in tariff Guaranteed price up to 5 MW
1994	2366/1994	Increased installation cap to 100 MW
1997	54/1997 Electric Power Act	Guaranteed grid access Introduction of “Special Scheme” or SR Set a target of 12% from RES by 2010
1998	2818/1998	RES producers were opted to choose fixed or premium tariff
1999	Plan for Renewable Energy PFER	New target 29.4% of RES by 2010, later changed to 30.3%
2004	436/2004	RES producers may sell to generators or directly to market
2007	661/2007	Introduction of a cap-and-floor system for RES-E

Source: Adapted from (Kreycik et al., 2011)

2.7.1.1 Evolution of PV Promotion Policy in Spain

In analysis (de la Hoz et al., 2010), it was argued that there were loopholes in the FIT policy right from its beginning. However, these loopholes were left unattended until a very late stage. Although more than 80% of the PV installed in Spain during this period was classified as ground mounted, 100% of them benefited from the FIT dedicated for rooftop PVS. This was due to lack of a monitoring mechanism that could differentiate the source of the electricity because it was all connected to a single input control structure. This eventually led to the failure of an attempt to introduce corrective actions to prevent such distorted PV deployments (de la Hoz et al., 2010). The RD 661/2007 condition of a one-year timeframe for terminating the program, later revised to a 1200 MW limit[5], led to a market rush to benefit from the 20-year FIT program, or government "commitment trap", which in turn resulted in a boom-bust cycle. The market collapsed in 2008 (de la Hoz et al., 2010). One of the most significant delays during the period of 1998-2008 was motivated by an administrative procedure that acted as a control action. This was intended to ensure compliance with regulated targets for electricity generation, whether purely technical (e.g. grid access), environmental, or territorial. These control measures were implemented by different administrations at local, regional, and national levels have proved to be highly complex. This was due in part to the considerable quantity of administrative procedures required in Spain. The time for the procedure required by a regional administration was estimated to take between 120 days to 24 months.

Two major factors behind this success were the broad social and political coalition leading to political commitment and continuity of support schemes, as well as the specific design elements of the support scheme itself. The FIT has been modified twice in order to accommodate concerns from different actors, particularly the government (regarding the financial impact of increasing RES-E generation on electricity consumers) and RES-E generators (regarding the continuity of support and "appropriate" support levels). The effectiveness of the Spanish FIT is often mentioned, and some publications have dealt with the details of this system (see, among others, Lopez, 2000; Dinica, 2003; Bustos, 2004; García and Menéndez, 2006; Bechberger, 2006; Meyer, 2007). If not all FIT systems are structured well enough, (Fouquet, 2007) and the Spanish FIT is praised for its effectiveness and cost-effectiveness in RES-E deployment, an analysis of this system is worth undertaking. In this paper, the main design elements of the Spanish FIT, and their evolution in successive reforms, are analysed. This issue is of utmost relevance because FITs are an obvious candidate on which to base a harmonized framework for RES-E support (Muñoz et al., 2007). This is a long-term aspiration of the European Commission, although the current approach is to allow the Member States to use the support scheme that best adapts to its circumstances and socioeconomic objectives. It is also relevant for those in particular countries, both within and outside Europe, who are

[5] The first economic framework proposal stated a limit of 1200MW of cumulative installation, with the first period ending in 28 September 2008. However, this was later criticized by the CNE as it was clear that cumulative installation was very close to this target even before September 2008.

discussing which promotion instrument to apply in order to encourage RES-E generation. The Spanish system provides real experience in this regard. Particularly useful for the implementation of FIT systems in other countries, is an analysis of how problematic issues related to an increase in RES generation, and how the (conflicting) interests and concerns of different actors have been accommodated. On the other hand, this analysis follows the recommendation of recent literature on the comparison between RES-E support schemes, which concludes that the specific design elements of support schemes, and not so much the type of support scheme being chosen, are the most important factors in their success (see Haas et al. (2004) and Huber et al. (2004), among others).

A political economy approach that takes into account the interactions between key stakeholders in RES-E promotion was used to interpret the actual outcomes of successive FIT reforms in Spain. This complements the analysis of FIT in other countries, which were carried out using distinct conceptual and methodological approaches.

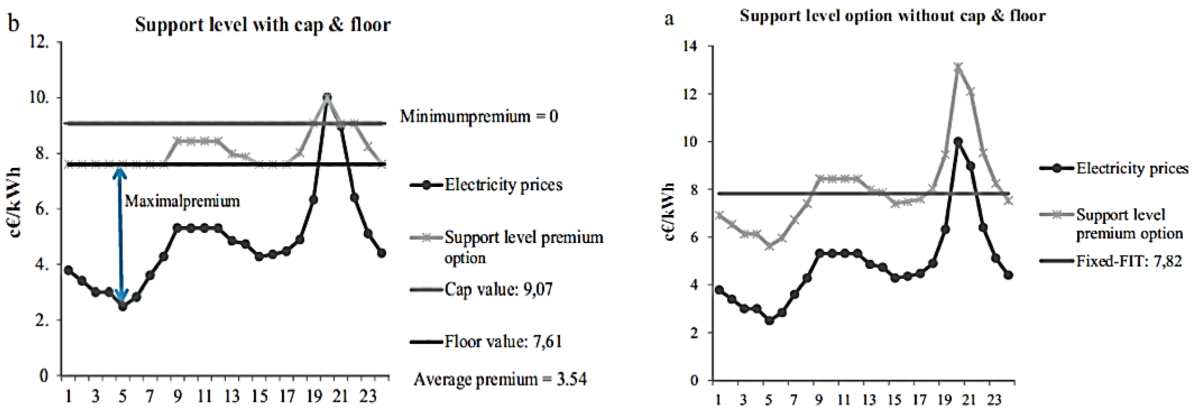


Figure 2-12: FIT with and without cap and floor

Source: (González, 2008)

2.7.1.2 Challenges for the FIT Policy in Spain

The Spanish feed in tariff experience includes the following expensive mistakes.

1. Removing the annual capacity cap

After the very high competition on the PV projects, the government removed the annual capacity cap to encourage the generation of more than 350 MW.

2. Setting a policy deadline and grid connection control

The royal decree in 2007 announced the termination (or suspension) of the feed in tariff policy and gave a deadline for projects to be completed (within eight months). Of course, this also resulted in breaking the trust of investors and developers in the market. What happened was there was a rush to install PV projects to exploit the high-level FIT before it was suspended or terminated altogether. As a consequence of the massive and sudden demand for human and material resources for PV mega solar projects, the costs of equipment rose drastically and did not decrease. More than 7.5 GW was installed in less than a year. Although costs theoretically would be expected to decline due to economies of scale, the manufacturers increased costs artificially to maintain a high level of tariff. Unfortunately, this was out of the sight of the authorities monitoring the situation. It is also worth noticing that the lack of grid-permit-control resulted in a significant impact on the Spanish grid stability (de Jager & Rathmann, 2008)

3. Grid connection monitoring

Because the FIT policy in Spain mainly targeted the residential sector (the notion of utility-scale PV projects was not popular back then: between 1998 and 2004). In order to exploit the high level of tariff set by the FIT policy for the residential sector, project developers used techniques to fool the system by fragmenting their large scale PV facilities into smaller ones to appear as if they were residential facilities of multiple small owners. When this discrepancy was discovered by the authorities, the minimum capacity required was redefined to be either less than or greater than 100 kWh. Developers then, however, integrated their small facilities to be just below the 100-kWh limit, to enjoy the highest FIT rate possible. Such unexpected policy-countering behaviours increased the proportion of expensive PV energy in an uncontrolled manner. Consequently, the cost sharing of the FITs turned out to exceed expectations (González, 2008; Miera, González, & Vizcaíno, 2008).

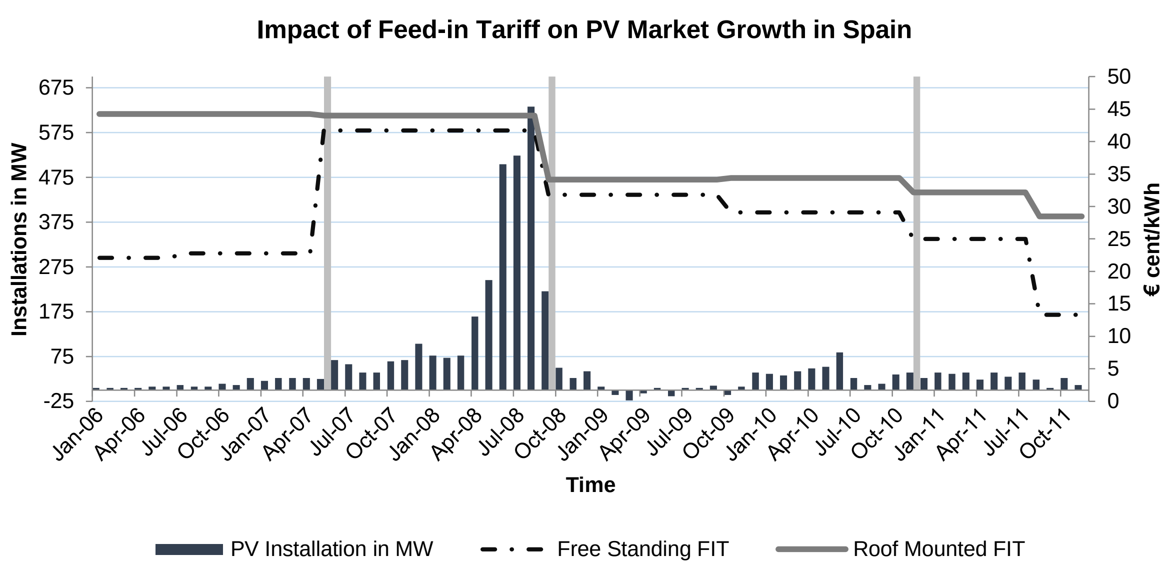


Figure 2-13: Impact of FIT on PV market growth in Spain

Source: (Jacobs, 2012b; Río & Mir-Artigues, 2012)

Such issues only could happen because of the lack of monitoring the typological source of the electricity fed into the grid. Hence, providing the proper mechanisms to ensure the right match of typology and corresponding policy compensation, are critical (de la Hoz et al., 2010)

2.7.2 Feed in tariff policy in Germany

There are a number of similarities between the German and Japanese cases, including energy policy, the nature of the manufacturing present, and the existence of an export-oriented economy. Similar to the Japanese case, the promotion of renewables in Germany started with the oil shock in the 1970s. Moreover, an energy diversification plan was enacted that mostly favoured nuclear power as the primary energy source. However, after the Chernobyl incident and with nuclear proliferation, opposition to nuclear fuel had risen, and public opinion shifted to favour environmentally oriented policies.

2.7.2.1 The Evolution of German FIT Policy

The promotion of PV energy and installation began with some incentives in the early 1990s with the 1000-roof project. This was gradually developed to 100,000 roofs. In 2000, the German Renewable Energy Act (locally termed the EEG) was formulated as the first innovative energy policy in the world. The policy was revised in 2001 and 2004 and later termed a Feed in tariff, where electricity was fed into the electricity grid (Volkmar & Lutz, 2004).

The policy significantly accelerated the deployment or diffusion of renewable energy and PV energy in particular. In fact, the policy created a solid incentive, and to some extent, a sustained demand. The PV FIT policy, supported by the cluster initiative in Germany succeeded in creating by far, the largest manufacturing industry in the world for PV modules as well as PV manufacturing machinery and complementary products like balancing systems (BOS) and mounting structures (Frondel, Ritter, & Schmidt, 2008). From another perspective, as the manufacturing process matured the cost of PV energy generation fell dramatically (Klein, 2012; Kreycik et al., 2011; Mendonça, 2012a; Pietruszko, 2006).

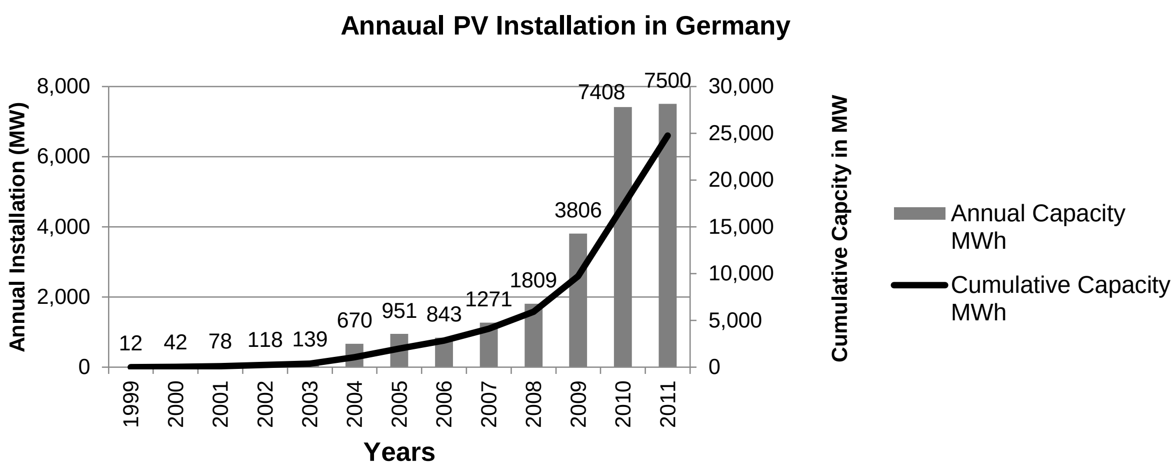


Figure 2-14: Annual and cumulative installed PV capacities in Germany 1999-2011

Source: (Frondel, Schmidt, & Vance, 2014)

As PV energy cost began to decline, some FIT policy adjustments were required to cope with the market and technology updates. Moreover, the larger the amount of PV energy installed and fed into the electricity grid, the larger was the FIT surcharge billed to electricity consumers.

2.7.2.2 Challenges for the German FIT Policy

This industrial growth, however, has faced several challenges, especially as facility installation climbed out of control. Some of these major challenges are listed below:

4. Alignment with the FIT Policy Goals

As the PV market started to grow, and the FIT price began to decline, the industry found ways to lower its costs and maintain its profitability. Manufacturing outsourced to China, and other countries were one option adopted by many PV companies. However, by doing so, the local manufacturers in Germany were challenged with a price war. Firms that outsource manufacturing were then criticized for seeking higher profitability by lowering labour costs and not by increasing technological efficiency through innovation and R&D (Frondel et al., 2008).

5. Grid Connection Control Measures

Although the policy had set an annual capacity target of 3.5 GW, the industry installed 7.5 GW for two consecutive years (2010 and 2011). This excessive installation was considered an unprecedented boost in the renewable energy world and was praised by the pro-environment media. On the other hand, these large facilities, with their large quantities of PV energy came with uncontrolled surcharge costs that impacted household electricity consumers substantially. In addition, opposition to the policy identified the effects of this uncontrolled installation on the stability of the electricity grid (Mabee, Mannion, & Carpenter, 2012).

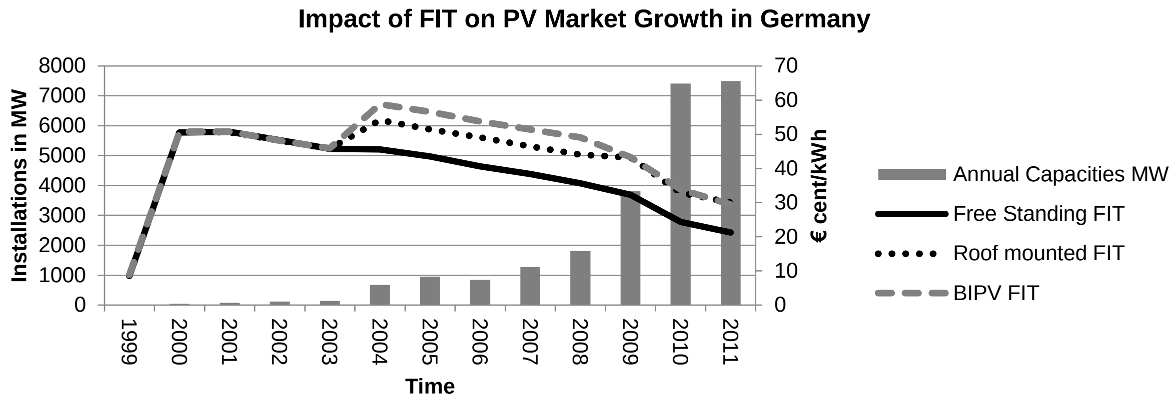


Figure 2-15: Impact of FIT on the PV market growth in Germany

Source: (Jacobs, 2012b)

6. Reactive Cuts to the FIT

The impacts mentioned in points one and two above resulted in reactive measures from policy makers. Unlike the FIT reduction case in Spain that led to a rush in 2008, the reactive measures in Germany involved significant reductions of the FITs prices without giving enough notice for project developers and manufacturers. The industry grew to its maximum size in 2011 to cope with the rapid local demand for PV projects, but the support reductions in 2011 slashed the demand significantly, creating a market shakeout. More than ten of the largest companies filed for insolvency because they could not cover their liabilities (Table 2-10) (Jacobs, 2012b; Takehama, 2012).

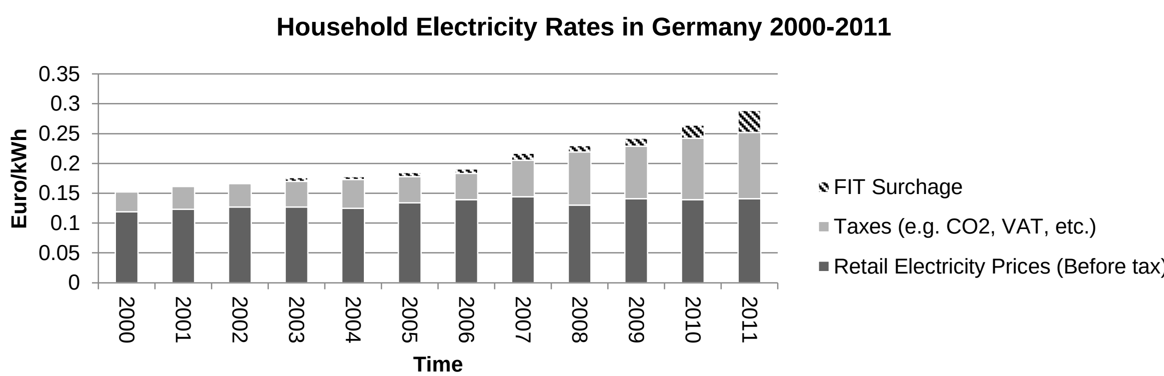


Figure 2-16: Household electricity rates in Germany

Source: (BMU, 2012; Eurostat, 2012)

Table 2-9: Annual Feed in Tariff Degression in Germany 2000-2009

Annual rates of Degression RES Act 2000 (effective 1 January 2002)	5%
Annual rate of Degression RES Act 2004 (applied 1 January 2005)	5%, 6.5% for ground-mounted systems
Annual Rates of Degression RES Act 2008 (applied 1 January 2009)	7%-11% as of 1 January 2010
Annual Rates of Degression RES Act 2011 (applied 1 January 2012)	9%-24% depending on market growth

Source: (Jacobs, 2012b) Note: (1) Degression for these technologies applies to both the base tariff and any applicable bonuses. (2) Responsive degression came into effect 1 January 2009. Source: Germany 2004, Germany 2005, BMU 2012

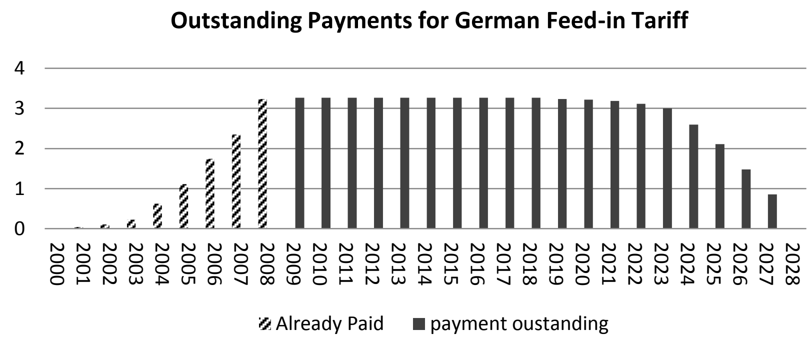


Figure 2-17: Outstanding payments for Feed in tariff in Germany

Source: (Frondel, Ritter, Schmidt, & Vance, 2010b)

Table 2-10: Bankrupted PV companies in Germany

Company	Bankruptcy date	Location
Solon	December 2011	Berlin, Germany
Odersun	April 2012	der Oder, Germany
Solar Millennium	December 2011	Erlangen, Germany
Sun Concept	February 2012	Germany
Ralos New Energies	February 2012	Germany
Solar hybrid	March 2012	Frankfurt, Germany
Sheuten Solar	March, 2012	Freiburg, Germany
Q-Cell	April 2012	Germany
Solvello	May 2012	Germany

Source: Author's compilation

2.8 Summary

This chapter has discussed the evolution of feed in tariff policy in Japan for the wind and solar energy markets. It also provided two case studies from two major markets in the field of feed in tariff policy design and analysis. The case studies provide significant lessons to learn from that can help in avoiding drastic mistakes that negatively affect national policy budget, renewable energy industry and electricity consumers or taxpayers.

3 Profitability Assessment of Solar PV Projects in Japan Under the Feed in Tariff Policy

Overview

Case studies from major markets in the previous chapters have shown that designing tariff levels that guarantees a minimum rate of return to developers is essential for market sustainability. The research found that high level of feed in tariff price could lead to market boom and bust. The Japanese feed in tariffs for solar photovoltaic technologies introduced in 2012 was found to be the highest in the world, creating intense criticism from observers and especially pro-nuclear parties. In this chapter, feed in tariff prices for photovoltaic projects are explored using a system dynamic model which analyses payback scenarios using the public data provided by the Japanese Ministry of Trade and Industry.

3.1 Introduction

Securing a profitable internal rate of return for long-term projects is an essential procedure in project decision-making. Renewable energy projects are still not viable without a support policy and subsidies. Furthermore, the implemented renewable energy policies like tradable green certificates and feed in tariff have a vital role in maintaining sustainable markets. The model in this chapter will discuss how the feed in tariff prices will affect the individual projects in residential and non-residential sectors. In Japan, the FIT policy was implemented in July 2012 and updated in April 2013 to cope with market updates. PV project cost estimation developed by METI is presented in Table 3-1. The policy has resulted in stimulation of market growth, which doubled at the end of 2012. However, given the urgency to fill the nuclear energy gap, various reports speculated that Japan was to be the 2nd largest market after the European Union. However, due to the complexity of developing and financing mega solar projects, manufacturers and developers focused on smaller projects (up to 50 kW). The complexity of developing utility-scale projects resulted from the following. First, the procedures required to obtain a grid permit were lengthy (up to three months). Second, the cost to rent land was high. This has led many developers to consider low-cost real estate, especially in and southern areas. However, the actual real estate value depends heavily on the local demand for real estate, as well as the population size of the city. With regions of relatively low population, the generation and grid transmission capacity for electricity were also relatively limited. Therefore, the third reason for the complexity of mega solar projects was inadequate grid transmission capacity between remote and major cities. Fourth, the resistance of utilities to accepting interconnection requests added higher risk to project completion.

These difficulties have shaped a unique market in Japan. To adapt to this new market structure, developers focused on small projects (systems up to 50 kW) with low risk and low-profit margins. A small PV system could be approved within three weeks and requires no regulation related to the high voltage grid. The Japanese PV market, as a result, has become one the largest markets for roof-top installation (Kaizuka, 2013).

3.2 Financing PV Rooftop Projects in Japan

PV rooftop projects vary in size depending on the area available area and the cost of the system. A bank loan is usually required to finance such projects. Banks require 20% of the cost to be paid as a down payment, with 80% funded by a loan. The interest rate is calculated based on the payback period as well as the risk margin associated with the project. It is being noticed that lower-cost modules like those manufactured in east and south Asia usually have higher risk margins and hence higher interest rates.

3.3 Methodology

A system dynamics model was developed to assess various payback scenarios. Although several software packages allows technical and financial simulation for solar PV systems, the model developed is unique as the structure of the model itself is highly customizable and scalable. The model was built on the pioneering work of an the Accounting System Dynamics by (Yamaguchi, 2013). Average output data from hypothetical solar systems were used. The model uses these data to calculate the revenues and payback period of residential and non-residential projects, using the feed in tariff prices announced by METI.

3.4 Sample Data

Solar irradiation levels and system monthly output data in kWh were obtained from satellite data provided by PVSyst software. The sample data were collected to achieve the ideal PV scenario, considering the technology and the orientation of the solar panels. Moreover, several locations were chosen to illustrate how solar irradiation differences affect power generation while using the same system setup and configuration. The samples had the characteristics. It is important to note that, in reality, achieving this ideal situation is difficult. It requires considering different house structures, orientations, and shading objects near the solar PV system. Moreover, a combination of different technologies with different efficiency levels can generate highly variable results.

Table 3-1: Simulated Policies in the SD Model

	Residential (FIT Switch = 0)	Non-Residential (FIT Switch = 1)
FIT rate (JPY/kWh)	38	36
Residential PV System Cost (JPY)	427,000	280,000
Maintenance (JPY)	7,400	10,000
Interest rate	2.5%	2.5%
Loan period	10 years	10 years
Financing	75%	75%
Percentage of power sold	70%	70%
Power degradation	5%	5%

3.5 The System Dynamics Model

A power-generation system dynamics model was developed to simulate the power generation of PV systems at various locations. Variables in green represent the locations where the solar projects are to be simulated. Using the tariff prices, the data of simulated energy output from the PV system (in kWh) is then converted into revenue. The

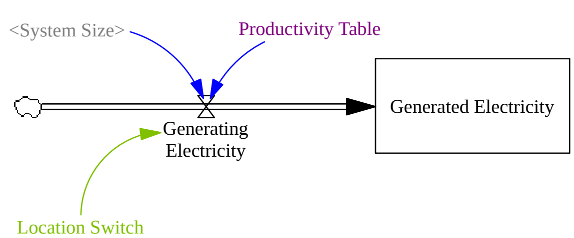


Figure 3-1: PV Electricity Generation SD Model

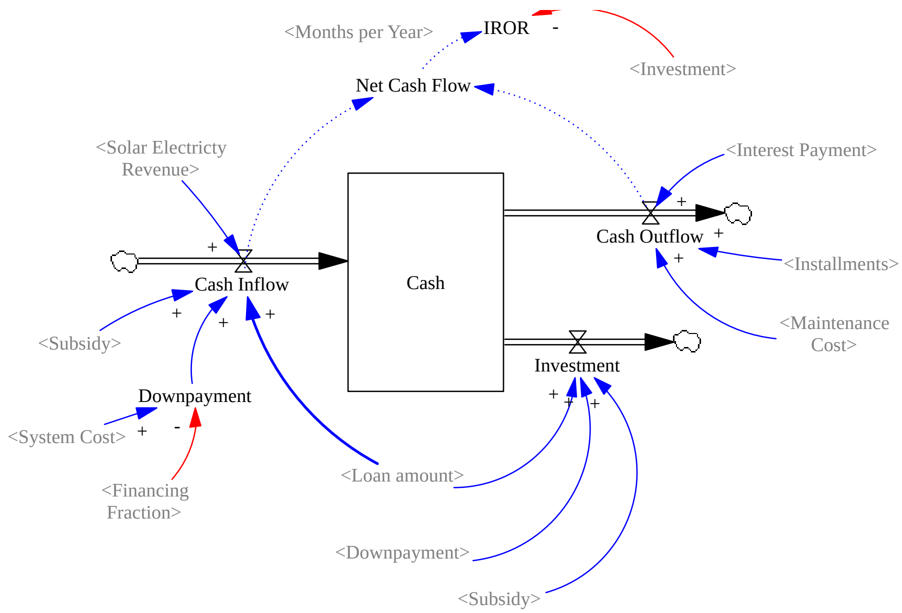


Figure 3-2: Cash Model

Variables in red show a switch that can be changed each time the model is simulated. A 1-kWh system was used for flexibility to adjust the system size. Yearly modulated table function was used to repeat power generation over time. Since in reality the system performance degrades over time, a productivity table function was used to replicate the degradation pattern in power generation. The accounting system dynamics model simulates simple double-entry accounting. It includes Cash stock on one side and liabilities (Equity and Debt) stocks on the other. The power generation flow is then fed into the accounting model following the double accounting principle. The loan and interest rate redemption is then subtracted from the revenues using the loan terms and interest rate level. An interest rate level of 2.5% is assumed . However, this rate actually highly variable depending on the financing entity and risk assessment of the project.

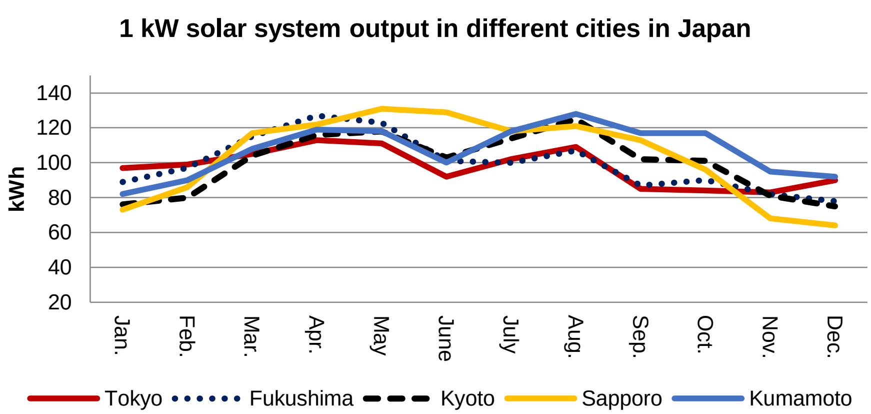


Figure 3-3: The Monthly output of 1 kW solar PV system for different cities in Japan

Source: PVSyst Software

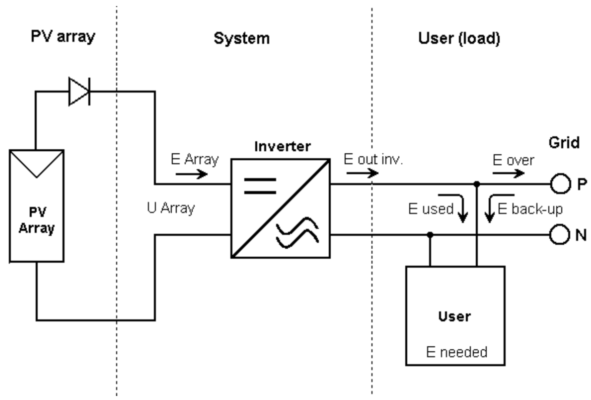


Figure 3-4: Circuit schematic for the system used in the simulation model

Source: PVSyst Software

3.6 Model Validation

The model was validated through the logical flow and causal relationship developed in the causal loop diagram models, as well as in the stock-flow models. In addition, the model was validated numerically by the introduction of a Balance Sheet Check (Yamaguchi, 2013) where the difference between Cash and Liabilities is expected to return a negligible value close to zero.

3.7 Model Assumptions

The model incorporated the following assumptions.

1. Because the feed in tariff policy guarantees the tariff price for the tariff term (15 years for rooftop applications), electricity generated from PV systems are assumed to be compensated at a market retail price of 24 JPY/kWh.
2. The power generation of panels is expected to degrade over time for two reasons: PV panel specifications normally guarantee output percentages for 20 or 25 years of production, and the overall system will exhibit some annual degradation due to depreciation.

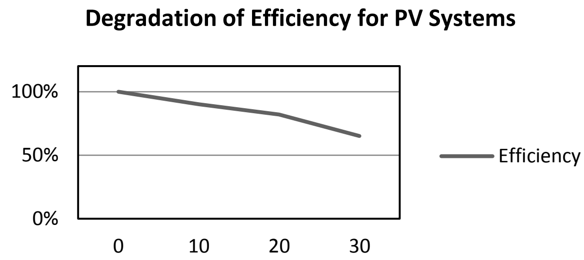


Figure 3-5: Estimated Efficiency Degradation for PV System

3.8 Profitability Analysis

The model has been simulated using multiple variations of the following parameters: Location (irradiation levels), Loan interest rate, Loan period, Self-consumption ratio, and FIT prices (2013 policies).

The profitability of PV projects was measured using the following economic metrics:

A) Payback Period

There are several definitions of payback period (Duffie & Beckman, 1980). However, two major payback period methods are presented below.

A.1) Simple payback time:

The time required for undiscounted PV net revenues to equal the initial investment cost (Paidipati, Frantzis, Sawyer, & Kurrasch, 2008; Perez, Burtis, Hoff, Swanson, & Herig, 2004).

$$Simple\ payback = \frac{PV\ Price - Subsidy}{Annual\ PV\ Revenues - O\&M}$$

A.2) Time to net positive cash flow (TNP) payback time:

The time required for i) the discounted PV revenues to exceed the discounted system costs accrued to that date, and ii) the discounted revenues to remain higher than discounted costs for the duration of the investment (Audenaert, De Boeck, De Cleyn, Lizin, & Adam, 2010; Nofuentes, Aguilera, & Muñoz, 2002; Sidiras & Koukios, 2005).

$$TNP\ Payback = \sum_{t=1}^{t=TNP\ Payback} \frac{Revenue_t - Cost_t}{(1+d)^t} > 0$$

and

$$\sum_{t=TNP\ Payback}^{t=N} \frac{Revenue_t - Cost_t}{(1+d)^t} > 0$$

The main difference between these two methods is that the simple payback period is not sensitive to the financing parameters or to the relative timing of the system costs and revenues (Drury et al., 2011).

B) Internal Rate of Return and IRR

The internal rate of return is the discounted rate at which project NPV equals zero, and frequently is the annualized return on investment (ROI).

$$IRR: NPV = 0$$

NPV represents the net profit generated by an investment calculated from the discounted sum of the future costs and revenues. When the NPV equals zero, the cost of PV-generated electricity is equal to the cost or value of electricity that could have been purchased from the grid, which is also known as "grid parity" (Denholm, Margolis, & Drury, 2009). The NPV is defined as:

$$NPV = \sum_{t=0}^{N} \frac{Revenue_t - Cost_t}{1 + IRR} = 0$$

NPVs, however, cannot be used alone to rank relative returns of investments with different costs. They are usually used with the Profitability Index (PI) or a Benefit to Cost B/C Ratio (Drury et al., 2011). The simulated policies using the SD model are shown in Table 3-1.

3.9 Results

3.9.1 Profitability analysis

Comparing the electricity generation of different locations, it appears that Fukushima actually has the highest rate of irradiation. This result is interesting when it comes to power supply and stability because Fukushima City is in a geo-critical region that was damaged by the great Fukushima earthquake.

The payback period will eventually depend on the solar irradiation at a given location. In the case of 100% sale of electricity, PV systems can be profitable with an IRR between 4.3% to 15% (Figure 3-8). However, systems are not profitable in the percent of energy sold is excessive. This is because the limit is dictated by the policy (40% of the generated electricity is the recommended percentage). This percentage of electricity to be sold is quite difficult to ensure due to the limited amount of power generation from the systems.

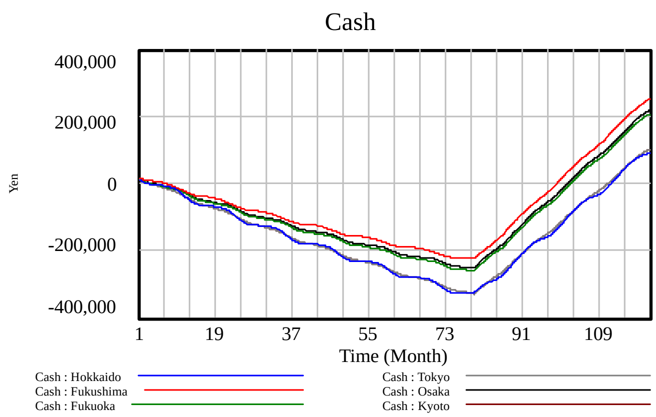


Figure 3-6: Cash and Payback Periods for Residential Systems

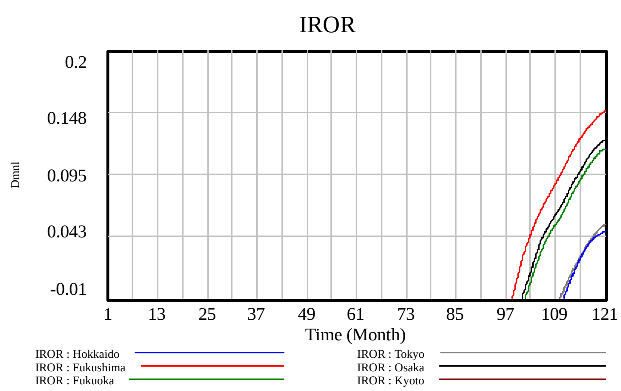


Figure 3-7: Internal Rate of Return for Residential PV Projects

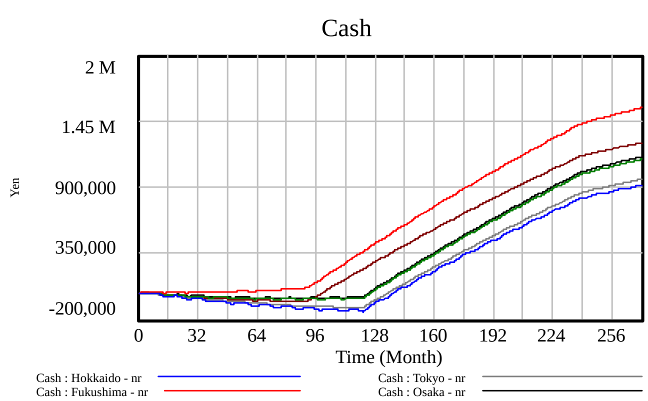


Figure 3-8: Cash and Payback Periods for Non-residential Systems

It is obvious that the METI proposal ignores some important factors that provide a more realistic estimation of IRR.

1. The project loan

Although rooftop projects are considered small, the interest rate and payment period are still significant parameters to produce a profitable IRR.

2. Project cost

Project cost may vary significantly depending on the project equipment and brands. The proposal seems to have averaged the Japanese branded projects. It is questionable whether banks really do increase the risk and hence the interest rate when financing non-Japanese brands to balance its cost with the Japanese branded projects. Considering the given average value in the proposal, various rooftop projects will not achieve a reasonable payback within the term of the given feed in tariff.

3. Regional differences

It is well known that weather data are necessary to estimate the power generation of PV systems. Regional weather differences that affect irradiation, and other parameters, should be considered.

4. Percentage of PV power self-consumption

Because rooftops can generate revenue only if they generate more energy than is consumed, it is critical to know what recommended self-consumption percentages would allow reasonable IRR. This would allow a reasonable payback period of the system, with some marginal return.

5. It is not clear from the data used from the METI reports whether the installation cost (within the maintenance cost) was included for residential and non-residential PV systems.

6. Maintenance costs for the non-residential sector seem to be very high (e.g., 3 million JPY/year for personnel costs).

7. The irradiation data used are for residential application and may be representative of large scale applications.

Profitability analysis for residential and non-residential projects uses different economic metrics, namely: Discounted Payback Period (TNP Payback), Internal Rate of Return (IRR) and Profitability Index (PI). The results show that systems with average prices are not profitable under the self-consumption policy. They are only profitable if the sales ratio is 100% (see Figure 3-9 and summary in Table 3-2). Moreover, energy storage may be required, but unless sufficiently subsidized, the energy storage system may increase the overall system cost. In addition, the 60% sales ratio scenario suggested by METI is not realistic, and cannot be profitable until the system cost is below 200,000 JPY/kW. Furthermore, depending on the location, profitability might differ significantly. Variation for the selected cities was 8–18% with PI, or 8–28% with the IRR metric. Based on that, it can be concluded that more than half of the installations added in 2012 will not be profitable, or that payback of the system cost can be achieved within 10 years.

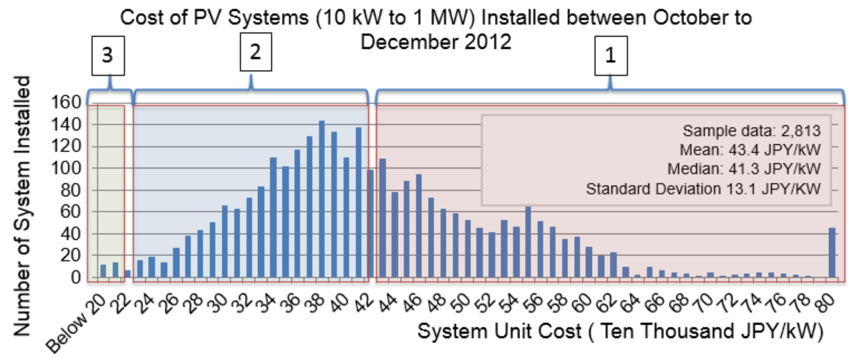


Figure 3-9: Distribution of PV system cost for the year 2013

Note: The feed in tariff price adjusted to the PV system costs to ensure the profitability and recovery basic costs within the commercial projects loan period of 10 years Source: (METI, 2013)

Table 3-2: Results of profitability analysis for residential PV systems

Group	Cost Range (JPY/kW)	Result
1	430,000 or more	Not profitable
2	220,000 to 430,000	Profitable at more than 80% sales ratio
3	220,000 or less	Profitable at 60% sales ratio

3.9.2 Future Pricing Policy

The model was used to answer the following questions. Is PV business profitable under the existing FIT policy**?** If the feed in tariff were an important factor for photovoltaic project profitability, what tariff level would be required to maintain PV profitability? Moreover, under what conditions would a feed in tariff make a PV project profitable? Designing optimized FIT prices could maintain the same level of profitability regardless of system cost. However, profit optimization requires setting profitability boundaries. For this reason, the following assumptions were made. First, an annual system unit cost and FIT price reduction at 10%. In addition, the minimum profitability rate should be IRR 7% or PI 4%, and the maximum payback period, for example, should not be more than nine years for residential systems. For non-residential systems, a minimum of 19% IRR or 36% PI will be needed, with a maximum payback period of 12 years. Based on these assumptions, the future tariff prices could be as illustrated in the following figures.

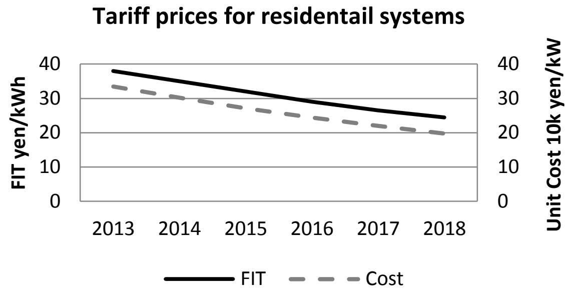


Figure 3-10: Future tariffs suggested by model for the residential sector

Note: The feed in tariff price adjusted to the PV system costs to ensure the profitability and recovery basic costs within the commercial projects loan period of 10 years

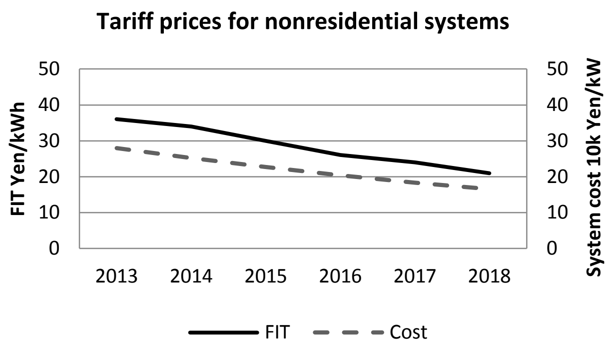


Figure 3-11: Future tariffs suggested by model for the non-residential sector

Note: The feed in tariff price adjusted to the PV system costs to ensure the profitability and recovery basic costs within the commercial projects loan period of 10 years

3.10 Summary and Conclusions

The feed in tariff policy is based on providing guaranteed return on investments. By adapting the FITs of Germany (the base model) and many other European countries, Japanese officials have reformed the feed in tariff policy to allow the sale of electricity from those applying to produce photovoltaic power > 20 kW. This was necessary to upscale the development of solar deployment. However, the reformed tariff level announced in Japan for solar photovoltaic applications was deemed too high by many critics inside and outside Japan. This could have had serious consequences. These claims were reviewed using government market monitoring data as well as market data for the cost of photovoltaic equipment and possible profitability levels.

A system dynamics model was developed based on the (Yamaguchi, 2013) accounting model. The model developed helped in assessing the profitability of feed in tariff prices for residential and non-residential solar energy systems and was used to compare scenarios for the years between 2012 and 2015. The return of investment is an important indicator for investors and individuals, and therefore, a reasonable level of profitability should be maintained. The future prices suggested by the model illustrate a mechanism by which the profitability rates are maintained within certain limits. Sensitivity analysis results showed a significant variation in the development cost for projects developed in major cities around Japan. Moreover, the cost of financing photovoltaic projects contributes a significant share to the overall cost of deployment. The reports published by METI about the cost trends in Japan showed a 10% reduction. The results from this study indicated recommended tariff levels that would maintain a sustainable return on investment.

With regard to residential applications, the feed in tariff policy suggests benefits from the sale of PV electricity remaining after self-consumption (use by the owner). However, these study results argue that it is difficult to recover system expenses (i.e. system costs, and installation and maintenance costs) using the data provided by METI. The market data confirms this conclusion, by showing panel price variation of Japanese versus non-Japanese PV panels. In addition, research revealed a significant increase in the sale of imported panels after the introduction of the new feed in tariff policy in Japan.

The following chapter will analyse how feed in tariff should be designed while considering the dynamics of PV market. After that, the impact of profitability on the supply of photovoltaic deployment will be analysed in the following chapter. It will consider maintaining the profitability of the projects by adjusting the tariff levels to the dynamic project costs with uncertainty.

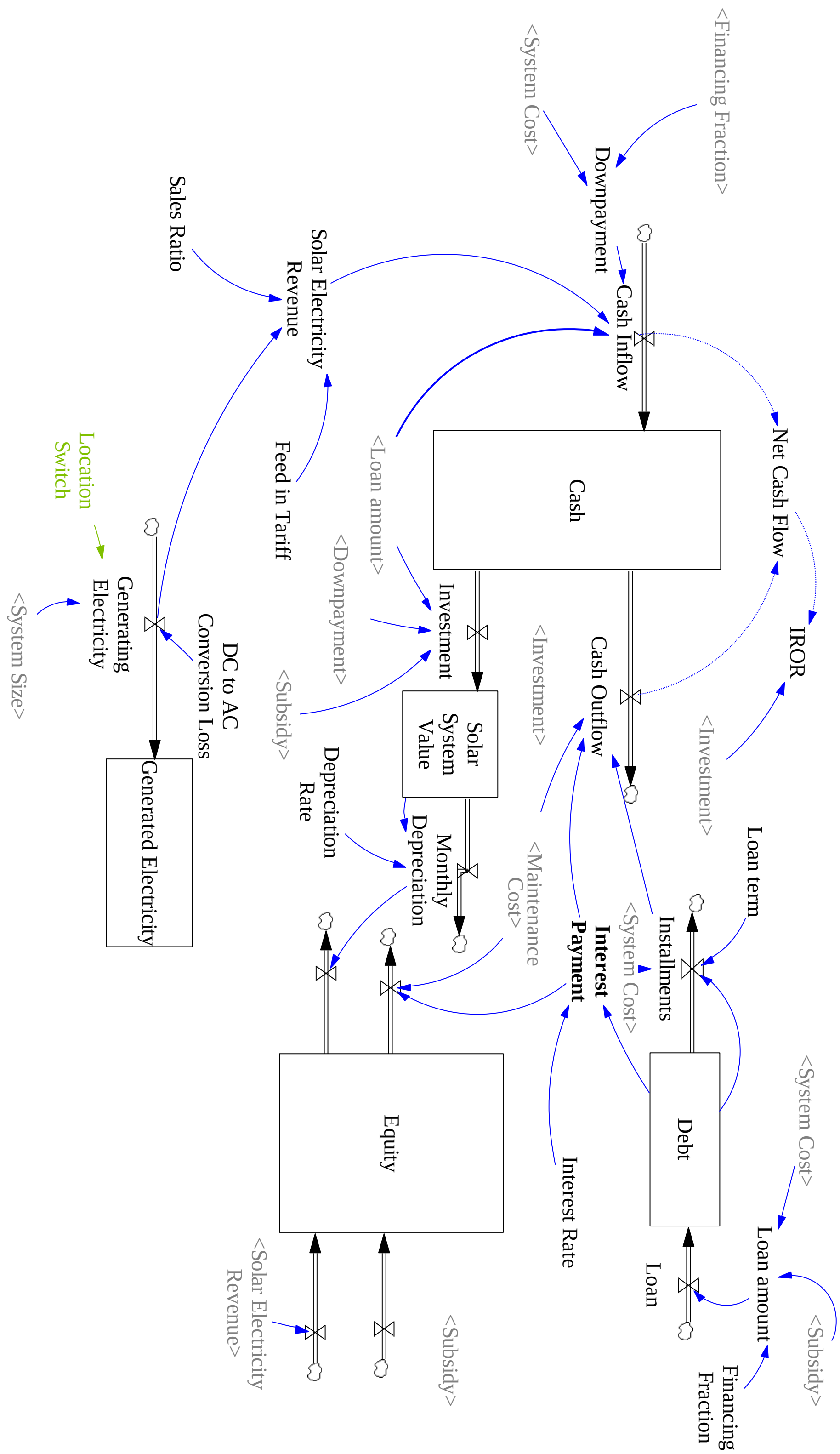


Figure 3-12: Profitability analysis stock-flow model

4 Designing Photovoltaic Feed in Tariff Policy Based on Market Dynamics [6]

Overview

Feed in tariff policy has been found to be successful in diffusing photovoltaic energy around the world. However, this success might come at the cost of the local photovoltaic industry. While the share of renewables might increase to reach national targets, market shakeout and a series of company bankruptcies often take place resulting in boom-bust cycles. Such market instability happens due to the frequency and magnitude of policy maker adjustments of the feed in tariff policy. By first understanding the dynamics of the photovoltaic industry, it is possible in this paper to discuss the development of resilient, responsive feed in tariff policy using system thinking conceptual modelling.

4.1 Introduction

The feed in tariff policy has been acknowledged for its success since the German experience starting in 2000. Unlike other policies, the feed in tariff provided a regulatory framework and high financial incentive to attract investors to invest in renewable energy. The result has been rapid growth in the diffusion of wind and solar energy generation. The feed in tariff experience, with variations, has been replicated in more than 100 countries and states around the world (Couture et al., 2010; REN21, 2012, p. 21).

The feed in tariff policy, as a result, is a very influential factor in the growth of the photovoltaic industry and in its acceleration. Because it provides long-term contracts, careful estimation of the feed in tariff price has to be carried out in order to reduce unnecessary payments and budget overruns. A poorly designed photovoltaic bill might create overruns in the billions, if not trillions, of dollars (Nemet, 2009). The FIT policy is primarily dependent on the cost of photovoltaic (PV) electricity. The complexity of the photovoltaic market, however, makes it difficult to estimate the cost of photovoltaic technology. The experience curve is a major tool that has been used to calculate the cost of technology, given a certain PV cumulative production capacity.

Previous feed in tariff experiences in Spain, Germany and Italy, have shown that the market might behave differently from what is supposed to and tend to exploit the feed in tariff policy in ways which are not aligned with the feed in tariff policy conditions. For example, the volume of installed PV capacity might

[6] This content chapter was presented at the Asia Pacific Conference for System Dynamics, Tokyo, Japan 2014.

exceed the announced target capacities, or the local PV prices might be actually be lower than expected or increased artificially (see for the case in Spain please see (de la Hoz et al., 2010; del Río González, 2008) and for case in Germany, please see (Frondel et al., 2008; Jacobs, 2012a; Wand & Leuthold, 2011) . For example, when the actual PV system cost decreases more rapidly than expected, it results in unreasonably high profit margins for PV electricity generators, or what is referred to as snowball effect, and so this urges the policy makers to introduce reactive policy measures to intervene and correct market behaviour. A sudden decrease in feed in tariff price or the suspension of the policy altogether are examples of these reactive measures that drastically impact PV markets and industries locally, regionally and internationally. Although policy makers currently overcome this challenge with continuous monitoring for the PV materials prices, and apply strict measures to the volume of installed PV, the feed in tariff policy adjustment model itself is rather inefficient and does not guarantee the prevention of oversupply in the deployments and taking reactive interventions to correct them.

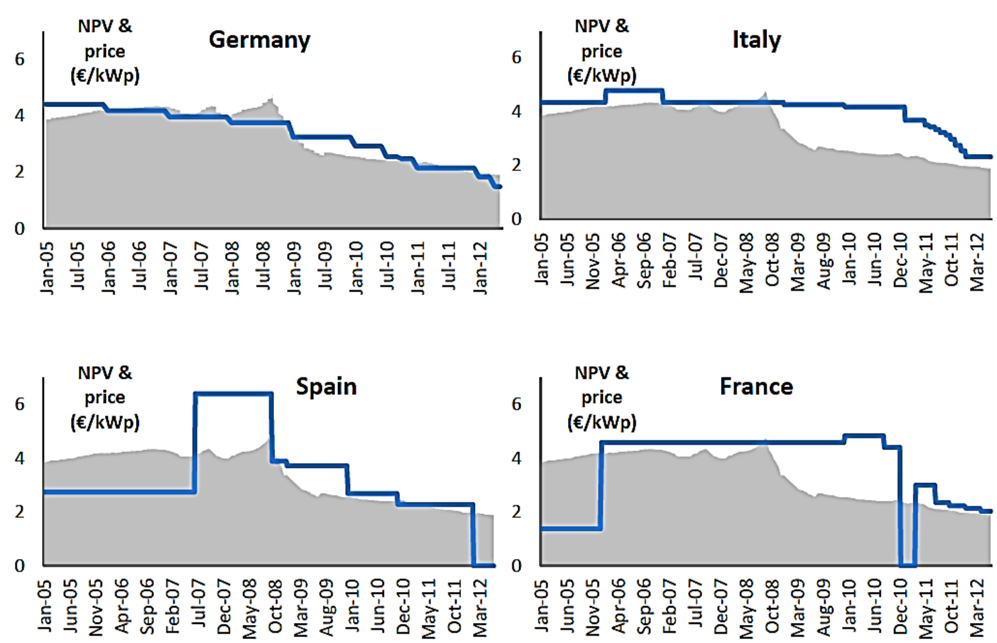


Figure 4-1: Feed in tariff experience in Germany, Italy, Spain, and France

Source: (A De La Tour et al., 2013)

In our view, the feed in tariff policy should be assessed according to how it can respond to internal or external changes. We argue that understanding the structure and dynamics of the photovoltaic market makes the design of the FIT policy much more efficient. System dynamics methodology was used in our model to analyse the structure of the photovoltaic market. The advantage of system dynamics over econometric and statistical techniques is that system dynamics can capture the structure of the system and by doing so, it can more efficiently predict its behaviour (Lyneis, 2000). Moreover, econometric models are limited in capturing feedback between the interdependent factors of the market and their temporal complexity (J. D. Sterman, 2000). These are crucial to observe, along with accurate estimates of the cost dynamics, and, therefore, crucial to setting the FIT pricing mechanism well.

4.2 Feedback Loop Analysis

The dynamics of the PV market can be represented in eight feedback loops Figure 4-2 and summarized in Table 4-1. The first loop, R1, illustrates the growth cycle in PV markets. A high feed in tariff leads to high business profitability, and this attracts local and foreign investors who file applications to install PV projects. The applications have to go through an approval process by the Ministry of Economy, Trade and Industry (METI) and the relevant electric utility. The approval cycle usually takes 3–6 months for projects of more than 2 MW, and 1–1.5 months for smaller projects. Approved projects are then installed to generate electricity. Moreover, based on the feed in tariff price a certain profit can be returned. As investors pile up applications to install more PV projects, the demand for PV materials increases. The increasing demand, in turn, signals manufacturers to increase their manufacturing capacity to fulfil orders on time. Therefore, the cost of developing PV project decreases based on an experience curve effect (Nemet, 2006) shown in the R2 loop (Figure 4-2). Inversely, if the manufacturing capacity cannot meet the demand, the cost of PV projects increases temporarily until manufacturing capacity adjusts. For full feedback loop, description refers to Table 4-1.

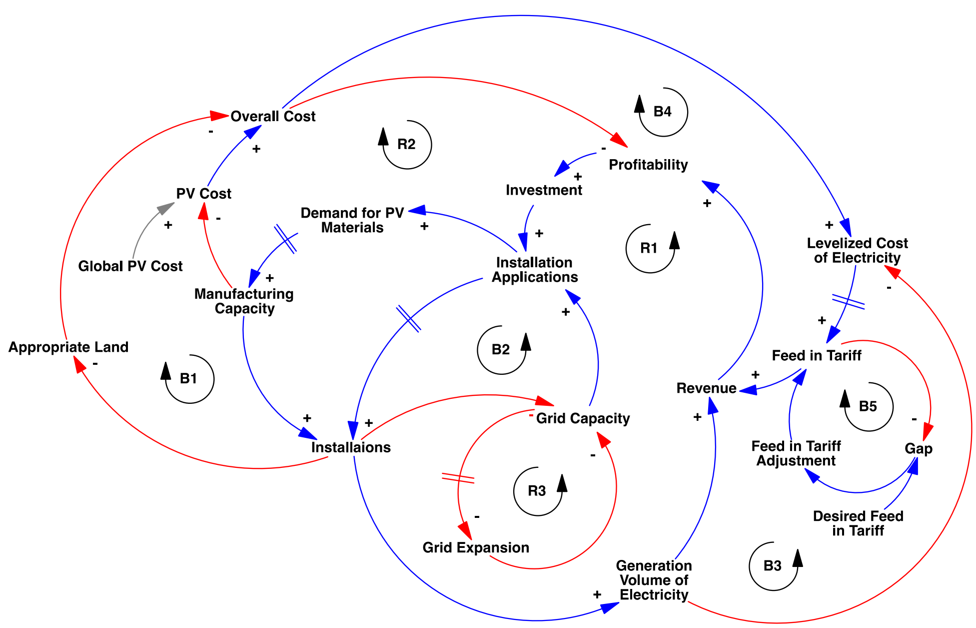


Figure 4-2: Causal Loop Diagram

Table 4-1: Causal Loops Diagram Summary

Loop	Name	Description
R1	Market growth	The more photovoltaic business is profitable, the more installations will take place, and more electricity volume will be generated.
R2	Experience Curve	As experience curve suggests, manufacturing capacity drives cost down and so profitability and market attractiveness increase.
R3	Grid Capacity Growth	Grid capacity expands to meet the demand.
B1	Land Utilization	With more PV installations, appropriate land for PV plants decreases and so the overall costs of PV increases.
B2	Grid Utilization	With more installations, grid capacity declines.
B3	Generation Volume	More installations result in more electricity generation volume, which drives the levelized cost of electricity down. Consequently, the feed in tariff is decreased accordingly.
B4 [7]	Overall Cost Effect	As the overall costs increase and the levelized cost of electricity increases, the feed in tariff should be increased accordingly.
B5	Feed in tariff Adjustment	The feed in tariff should be adjusted to reach the desired feed in tariff level, which occurs when the levelized cost of PV electricity matches the equivalent cost of fossil fuels.

Source: Author analysis

The growth of PV installations is constrained by several factors. The first constraint is the grid capacity, which is illustrated in B2. The grid capacity constraint actually comes in two forms: the transmission capacity and the grid geographic coverage or reach. The transmission capacity constraint happens when the transmission capacity between utilities is limited. For example, many areas in Hokkaido prefecture were found to be attractive locations for PV power plants considering the land cost and other land characteristics. Toru Suzuki, the chair of the non-profit Hokkaido Green Fund said, "No growth target for renewable energy would be feasible without Hokkaido", thereby emphasizing the competitiveness of Hokkaido and at the same time, the scarcity of appropriate land in Japan for renewable energy projects. Between April 2012 and March 2013, around 1.53 GW of capacity was approved by METI, and filed for grid connection with Hokkaido Electric Utility. However, because this supply of electricity greatly exceeded the anticipated demand in Hokkaido Prefecture, much of it would have been sent through

[7] Note that B4 can also be a reinforcement loop if the outer loop is considered.

transmission lines to neighbouring prefectures. However, the transmission line capacity was found to be insufficient, and the Hokkaido utility was forced to reject 70% of the applications filed (Asahi Shinbun, 2013; BNEF, 2013b).The other grid constraint is related to geographic coverage of the grid. As large-scale solar developers target affordable and appropriate land far from major cities, the distance from the grid becomes further; so the substantial grid connection cost makes such projects infeasible. Moreover, building connections to distant locations takes time that might result in excessive delays for these projects (Sasa, 2013).

The second major constraint is appropriate land. Appropriate land for solar projects must fulfil certain requirements: acceptable rent or cost, acceptable soil or ground type, southern exposure, flatness, having minimum shade from the surroundings, and proximity to a grid. The more appropriate the land is initially, the less additional expense will be required to adapt it. The rent or purchase of land in Japan is known to be very expensive. However, as B1 suggests, as more PV projects are completed, there will rapidly become less appropriate land; so the overall cost of PV projects will increase, making new PV projects less profitable (Sasa, 2013). Loop B3, B4, B5 are related to the factors that influence feed in tariff pricing. The Levelized Cost of Electricity (or LCOE) was calculated based on loops B3 and B4. The LCOE is an important measure that is used to estimate the cost of electricity generated by solar PV. Moreover, PV electricity generators are compensated based on this cost. With more PV installation, the overall cost of PV decreases with ongoing investment and the supply of the PV electricity generated increases. This in turn encourages policy makers to step down the feed in tariff accordingly. B5 explains what is called FIT degression. The feed in tariff is intended to be lowered smoothly until the LCOE of PV reaches the LCOE of conventional energy sources.

4.3 The Market Structure

The stock-flow model describes the structure of PV market dynamics in Japan through the aging chain illustrated in Figure 4-3. The birth of a PV power plant starts with applications submitted to METI and ends with a functioning PV power plant. When the market is profitable and attractive enough, investors or PV project developers submit applications to METI for approval. The process of filing a solar project usually starts with a consultation with the relevant utility. Next, a permit is needed from the Ministry of Trade, Economy, and Industry. Finally, a request for a grid connection is made to the relevant utility. The average time to obtain the required approvals varies from 3 to 6 months depending on the project details. Applications that do not satisfy project standards are usually rejected.

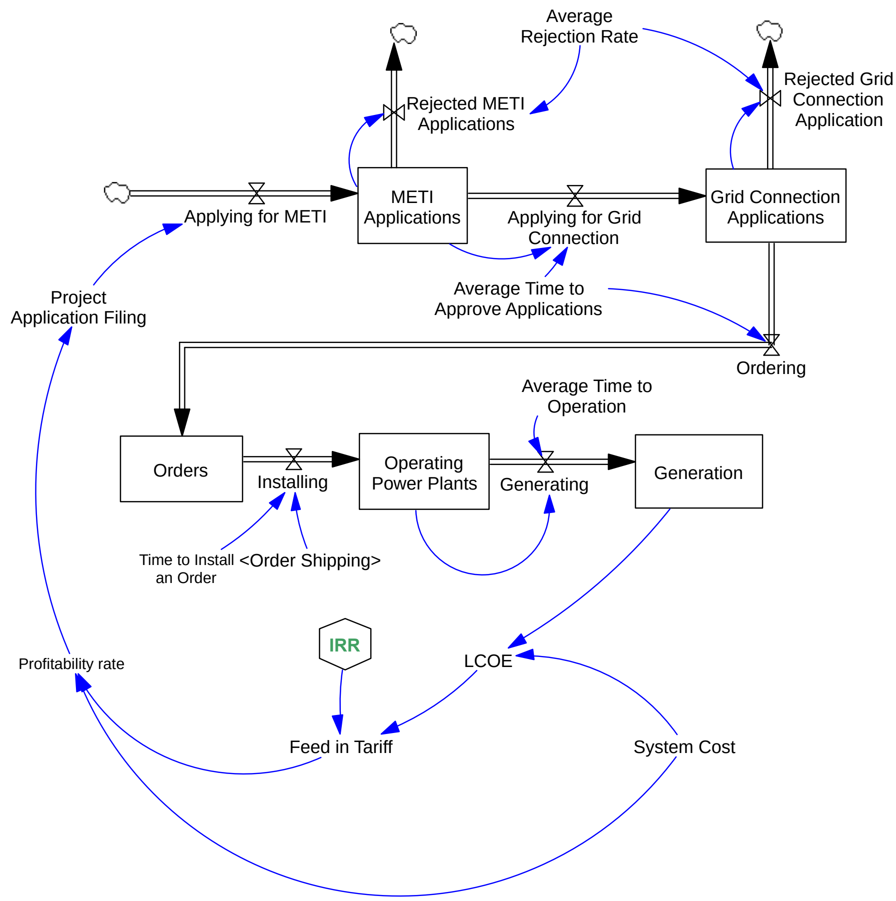


Figure 4-3: Basic Stock-Flow Model

Source: Author's drawing

Applications approved by METI are then submitted to the relevant utility. Depending on the grid condition, project applications are accepted or rejected. With every application approved for connection to the grid, the unused grid capacity decreases. Moreover, when the grid capacity becomes insufficient for the anticipated demand and supply, grid expansion is scheduled (see Figure 4-4).

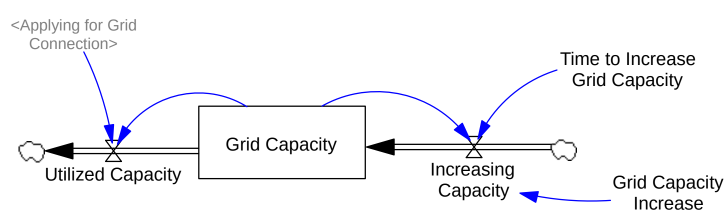


Figure 4-4: Grid Capacity Stock

Source: Author's drawing

Once applications are approved for connections, project developers then order the power plant materials from manufacturers. Due to the abundance of PV panels available from local and foreign companies, the procurement of panels is not a real issue for PV projects. However, the procurement of power conditioners is quite challenging, because such orders might take up to six months for delivery[8]. The power conditioner is actually a key component of solar PV projects without which the entire plant cannot be connected to the grid to transfer the electricity generated. The plant cannot generate any revenue until the power conditioners are in place. Once the power conditioner is installed, and the power plant connected, the operation of the facility has to be tested for one month to verify safety, protection, and standards compliance. However, as orders increase, the manufacturing capacity has to grow to cope with the market demand. Once the materials are delivered to the site, the installation work starts. The average time to install the PV panels of a mega solar plant is usually 1.7–2.7 years (Izadi, 2013).

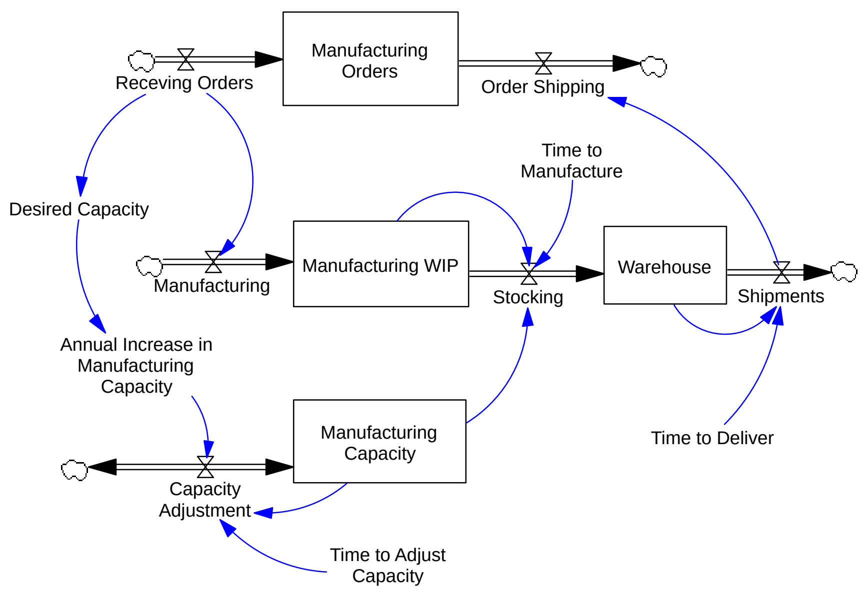


Figure 4-5: Manufacturing Capacity Dynamics

Source: Author's drawings

The manufacturing capacity stock is important in this model as it shows the accumulation of manufacturing capacity scale over time and also the rate at which PV industry can fulfill the market demands. In the same time, it helps to estimate the PV cost using the experience curve models (Nemet, 2006). The experience curve is then can be used as a mechanism to project future costs of PV modules and other related technologies and estimate the levelized cost of electricity of solar PV power plants. Ultimately, based on the figures derived from the model, the feed in tariff price can be adjusted to the

[8] The power conditioner is electrical equipment required to invert the DC current produced by the panels to the AC current used in the grid.

market data. The model provides extensive insights in understanding market attractiveness and profitability from an investor point of view and measure the sustainability of the market.

4.4 Analysis

The model provides a simple approach to understanding the market dynamics for the photovoltaic market in a holistic way. The stock and flow model can capture the flows and material delays within the system, making it is easy to experiment with the PV-market growth rate and size, relative to time. Similarly, designing a mechanism that dynamically sets the feed in tariff at equilibrium is likely to be more efficient and to make the policy more resilient to external and internal changes. The model can help in managing the time complexity between the interdependent factors within the described system and help policy makers to make a decision in overcoming the market growth constraints in right time. For example, while the transmission line was under expansion in congested areas, other areas might be promoted for even distribution of PV installations by subsidizing the grid connection cost. Another example to deal with growth constraint is related to project resources. The cost of project resources (whether it is projected materials like panels or resources like land) could be bounded by an upper limit to avoid price spikes that arise from temporary periods of high demand. Resources with a cost outside the range could be subsidized to ensure a minimum level of profitability.

In addition, the model captures the supply and demand within the market. Whereas the manufacturing capacity and stocking capacity can show market supply, the stock and material orders from METI applications indicate market demand. Therefore, the model can estimate PV pricing in cases of over stock or under stock situations. More importantly, the model can simulate the effect of the feed in tariff on the industry and its plans for expansion. Therefore, as the model illustrates the full picture of the market, better-informed policy makers could be more careful about taking reactive measures that could negatively affect the market.

4.5 Future Research

The existing conceptual model in this chapter uses simple structures for capacity growth for the sake of simplicity. However, these structures can be enhanced with more sophisticated model structures that are well known in the system dynamics literature for supply chain management and cost management. Such enhancements in the model can lead to more efficient and responsive results however it might may increase the complexity of the problem and diffuse the objective of this study. In addition, the model was based on the Japanese PV feed in tariff policy and photovoltaic market, however; further comparative research will be required to generalize the model to other renewable energy supporting policies or other renewable energy markets other than photovoltaic. Moreover, the conceptual model is the first to shed the light on the interaction between the renewable energy promotion policy, the renewable energy market and industry and provide a basis for future study in assessing the impact of applying different policies on those three elements. The model scope can be extended to include the impact on employment and provide extensive insights evaluating the policy performance in achieving its extended objectives that include green job employment.

4.6 Conclusions

This chapter has investigated the long-term impact of feed in tariff policy on renewable energy development using a case study from the photovoltaic energy sector in Japan. The study devised a conceptual model based on system thinking principles. The model aims to provide a feed in tariff mechanism that is efficient and responsive developed based on market and industrial dynamics. The system thinking model developed in this chapter aims to help the policy makers in designing the feed in tariff policy which adjust dynamically to the market dynamics. The model also guides policy makers to extend to the renewable energy policy objectives and support a balance between local and supply and demand. The system thinking process followed identify logical interaction and responses between entities of the elements of the study while considering feedback response and time delay. Identifying the major feedback loops in the problem were essential to understanding market growth, pattern, constraints and bottlenecks. The conceptual model developed contributes to provide a holistic understanding of the market where feed in tariff policy can be experimented to develop a resilient, efficient and responsive feed in tariff policy.

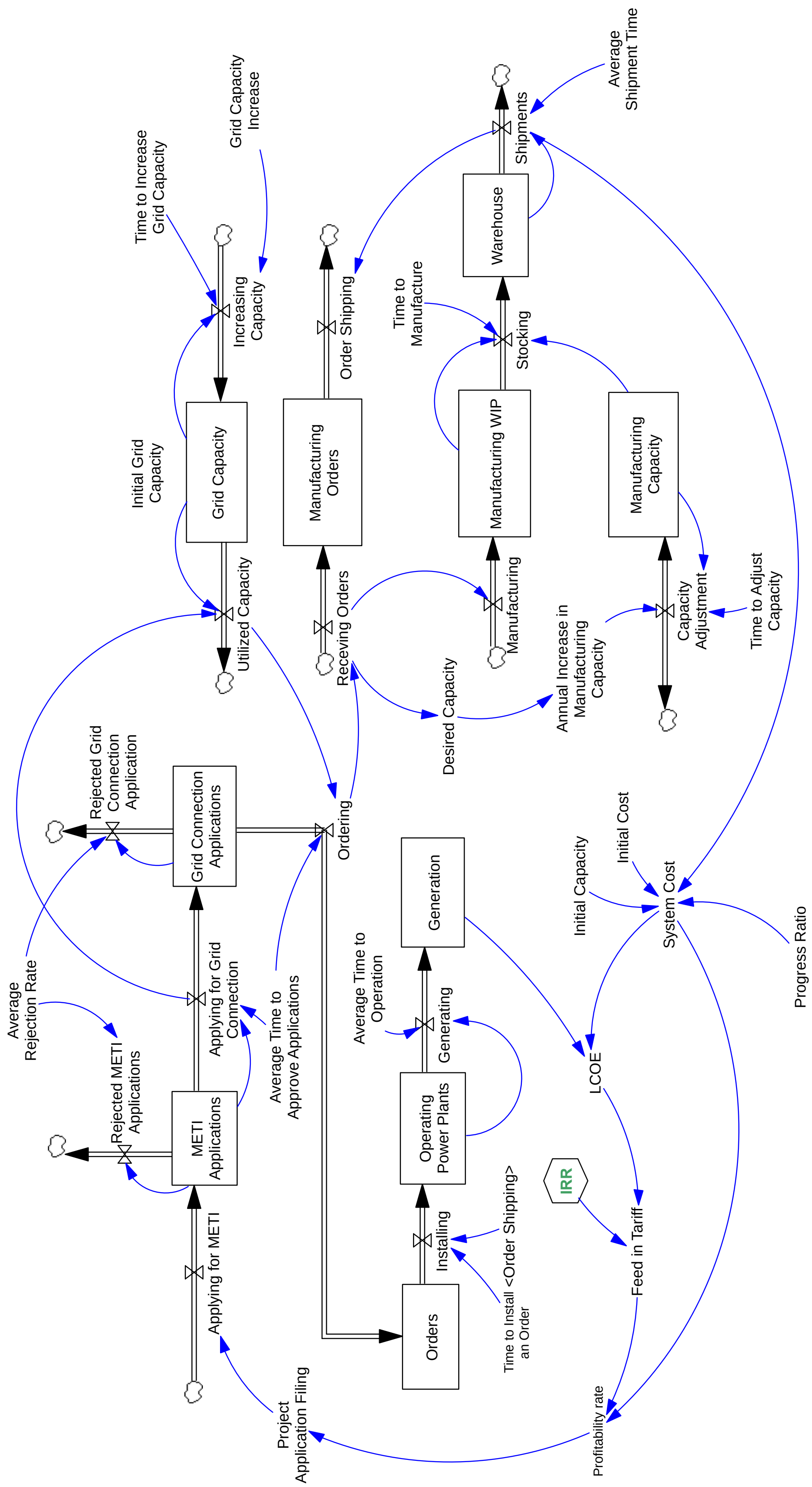


Figure 4-6: Complete stock-flow conceptual model

5 Dynamic Feed in Tariff Price Adjustments for Rooftop PV Market in Germany

Overview

Here, the feed in tariff policy for the rooftop photovoltaic market in Germany is discussed, and an attempt is made to explain the fluctuation pattern of PV deployments that occurred between 2011 and 2014. The study was intended to figure out the basic structure of the system behind this phenomenon, and to suggest a way to reduce fluctuations and stabilize the growth of the PV market. The system dynamics method was used to build a simulation model as an alternative to the optimization method used in earlier research. The simulation model successfully replicates historical behaviour. The model results were then analysed to enhance feed in tariff policy design to have a dynamic and real-time feed in tariff policy instead of a stepped, discontinuous one. The study concludes that dynamic price adjustments can significantly improve the stability of market growth. Dynamic price adjustment can provide a more cost-effective policy and provide reliable market projections for policy makers.

5.1 Introduction

The feed in tariff policy is recognized as the most effective policy for stimulating the rapid and sustained growth of renewable energy (Klein, 2012; Martinot & Sawin, 2009; Mendonça, 2012b; Ölz, 2008). It succeeds in providing an effective supply of renewable energy at a lower cost than other policies (de Jager & Rathmann, 2008; Fouquet & Johansson, 2008; Lipp, 2007; Menanteau et al., 2003; Ragwitz et al., 2007; Stern, 2007). The European Commission indicated that “well-adapted feed in tariff regimes are the most efficient and effective support schemes for promoting renewable electricity” (European Commission, 2008). The policy has also been successful in reducing the cost of technology, by increasing technological efficiency and innovation in its related industries (Campoccia, Dusonchet, Telaretti, & Zizzo, 2014). The core principle of FIT policy is the guaranteed tariff price for a fixed period during the time in which the renewable energy facility is operating. The tariffs are paid for each kilowatt-hour (kWh) fed into the electric grid. In most tariff-scheme designs, the tariff price is determined relative to the cost of electricity generation (European Commission, 2008, 2008; Klein, 2012). This is also referred to as the Levelized Cost of Electricity, or LCOE. Basing the prices on the costs required developing renewable energy power plants, and guaranteeing payment over the operational lifetime of a power plant could reduce investment risks substantially. This structure could increase investment security by providing predictable project cash flows and maintain the visibility of the payback period, especially when considering the high upfront investment cost for renewable energy projects (European Commission, 2008; Guillet & Midden, 2009;

Lipp, 2007). Moreover, the FIT structure allows decentralized energy development with large participation from residential, commercial, and agricultural sectors. Unlike other policies (e.g. tendering schemes), the standardized feed in tariff scheme can significantly reduce the administrative procedures that facilitate rapid market growth in the renewable energy industry. For example, the number of independent solar projects in Germany reached 1.5 million by the end of 2014, something that would have been resource consuming and extremely infeasible, if done without a standardized tendering process (Fraunhofer, 2014; Scheer, 2013).

The tariff pricing is differentiated based on a number of factors, like the type of renewable energy source, its technology, the size of the power plant, the location of the power plant, and many others (Fouquet & Johansson, 2008; Klein, 2012; Langniß et al., 2009; Mendonça, 2012b). The policy contract lasts between 10 and 25 years (the contract period is also referred to as the feed in tariff term). As cost declines and technological efficiency increases, the feed in tariff prices are adjusted downward accordingly until the end of the feed in tariff qualifying period, to guide the market development as intended. The rate of reduction of feed in tariffs are called degression rates and are determined by the authority in charge of the policy (Klein, 2012). The degression rate should be adjusted to the feed in tariff prices that reflect actual market costs. However, setting the appropriate degression rate is challenging, considering the dynamic cost development of renewable energy technologies. Economies of scale, potential for technological innovation, and market supply and demand are some of the factors that influence the technological cost development.

Germany is one of the first countries (in the year 2000) to implement a feed in tariff policy (or in German called the EEG, which stands for Renewable Energy Sources Act, or "Erneubare Energien Gesetz" to boost the development of renewable energy. This came as part of the ambitious, long-term decarbonisation plan of the Bundestag (German parliament). Creation of the FIT policy was based on the decision to gradually abandon nuclear power and decommission all nuclear power plants by the year 2022, although Chancellor Merkel has extended this target to 8–12 years (Deutsche Bank, 2011). As of the year 2012, the nuclear energy in Germany accounts for about 23% of the total energy mix (Pfaffenberger & Chrischilles, 2013). The effect of the feed in tariff policy has been substantive as the share of renewable energy in the energy mix has risen more than threefold between the years 2000 and 2010, from a mere 2.9% to 10% (BMWi, 2015). The aim is to continue the increase in the targets of 38.6% by 2020, and 80% by 2050. Solar PV energy has shown unprecedented growth (~ 115 MW in 2000 to > 38,200 MW by 2014) and constitutes about 6% of the current energy mix (BMWi, 2015; Fraunhofer, 2014). It is estimated that this renewable energy roadmap will reduce the greenhouse emissions by 80–95% below 1990 levels (Deutsche Bank, 2011; Fulton, Capalino, & Auer, 2012).

The German government introduced the concept of capacity corridors to guide the development of energy supply within 2.5–3.5 Gigawatt (GW) per year (Deutsche Bank, 2012b). Nevertheless, the deployment in the years 2010 and 2011 exceeded 7.5 GW. Such unexpected market response required urgent policy intervention because the unexpected rate of change might have increased the budget by billions of dollars (Chowdhury, Sumita, & Islam, 2012; Frondel et al., 2014).

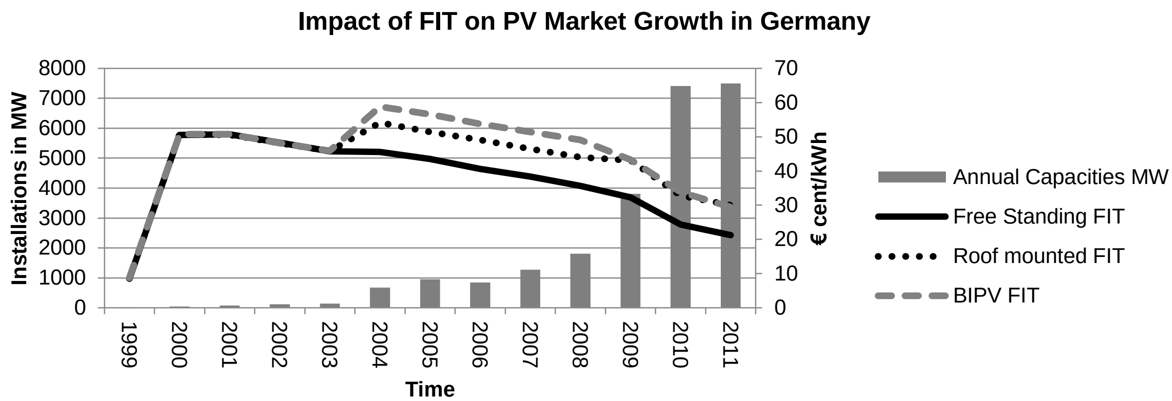


Figure 5-1: Impact of FIT on PV market growth in Germany
Source: (Jacobs, 2012b)

Because the feed in tariff policy budget is paid by electricity consumers and taxpayers, an unexpected increase in the renewable energy supply could result in sudden spikes in electricity prices or taxes (Frondel et al., 2008). The fact that feed in tariff policy is a long-term contract creates a policy trap for governments and might create a long-term burden on the public. Therefore, missing the right time to adjust the feed in tariff prices results in a substantive increase in the cost of the policy (Jacobs, 2012b; Nemet, 2009). It is much better to adjust the feed in tariff policy dynamically and efficiently. The rooftop PV market in Germany constitutes about 30% of all PV installations in Germany. Thanks to high levels of the feed in tariff, the cost of rooftop PV systems in Germany has witnessed a continuous decline. However, the pattern of rooftop PV follows a cyclic pattern, with spikes before price adjustments. This pattern appears as project developers observe the declining cost and wait for the best time to install their projects, or they rush to install more projects at the end of a qualifying period (Grau, 2014b).

Unlike large-scale photovoltaic projects, small-scale projects have shorter development time and hence respond more quickly to policy changes. The rush-to-install behaviour is explained by three observations: 1) deployments increases in proportion to profit levels, 2) profit expectations decrease over time, and 3) deployment accelerates right before the tariff price adjustment deadlines to benefit from the highest tariff prices, creating a rush-to-install effect (Grau, 2014b). According to the estimates, a rooftop PV installation project has a construction time between 3 and 15 weeks, and averages seven weeks.

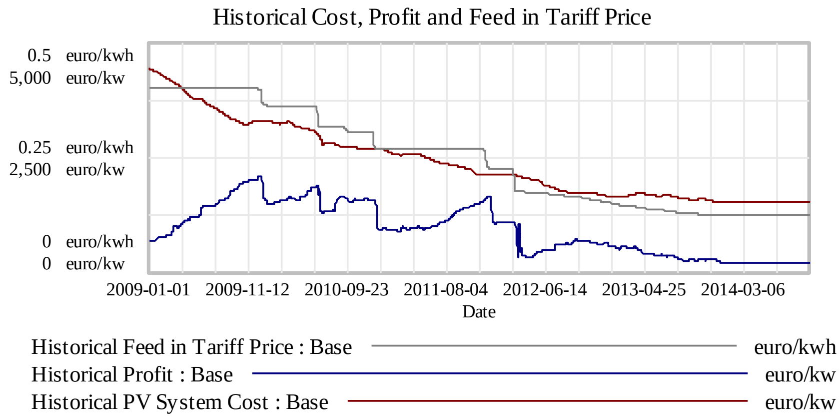


Figure 5-2: Feed in tariff is adjusted to cope with declining PV system cost

Source: (Grau, 2014)

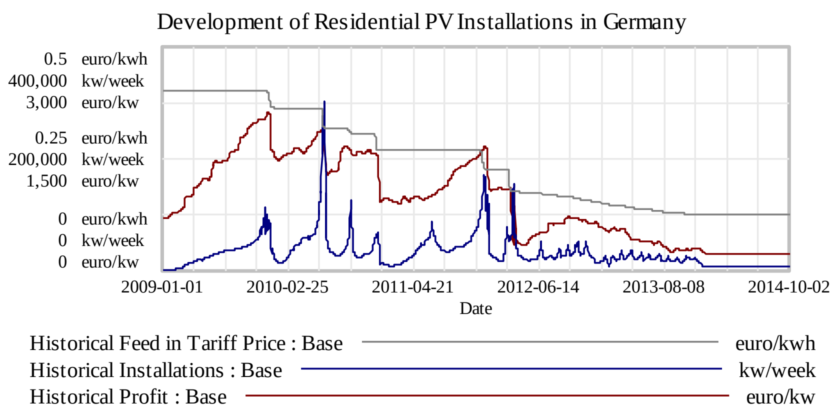


Figure 5-3: Weekly deployment levels of photovoltaic projects in Germany

Source: (Grau, 2014)

5.2 Grau's Model

A regression model was used to estimate deployment based on the profit level. The model was enhanced to model the rush-to-install effect using an optimization technique, according to which developers would decrease construction time to the minimum possible to ensure the highest level of profitability. Although the results obtained from the optimization model replicate historical patterns fairly well, the model has a shortcoming that it does not incorporate developer expectations of cost and price adjustments, nor the delay needed to form these expectations. Therefore, the model assumes perfect decision making by PV developers. As explained by (J. Sterman, 2000) optimization techniques consider perfect outcomes and ignore the operational processes of decision making, as well as imperfections and the bounded-rationality effect. In the (Grau, 2014b) model, the installation rate was calculated using:

$$Y_{t+d} = \alpha * \pi_{t+d} - c$$

Where, Y_{t+d} is the installation quantity, π_{t+d} is the profit, and α and c are parameters. The net profit is given by:

$$\pi_{t+d} = v_{t+d} - p_t$$

Where, v_{t+d} is the present value, and p_t is the average system cost. The present value is then formulated as:

$$v_t = f_t * h * \sum_{j=0}^{n} (1+i)^{-j}$$

Where, f_t is the feed in tariff price at time *t*, and *h* is the average operational hours per a year, *i* is the interest rate, and *j* is the feed in tariff term. The feed in tariff price data are given in the Figure 5-2; facility operational hours were estimated to be around 900 kWh/year in average. The interest rate was assumed to be fixed at 3.5%, and the feed in tariff term for residential roof top photovoltaic projects was set at 20 years.

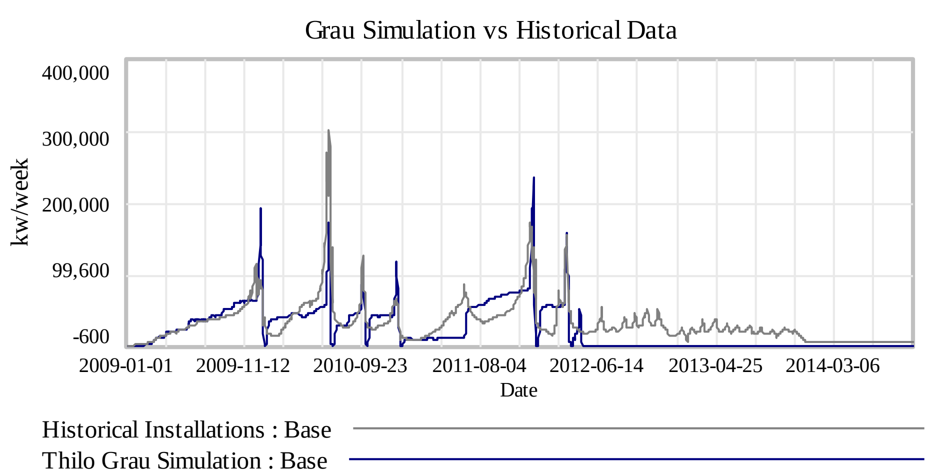


Figure 5-4: Comparison of (Grau, 2014) simulation and weekly historical installation of rooftop PV in Germany

Source: Author's drawing with data obtained from (Grau, 2014)

5.3 System Dynamics Approach

The causal loop diagram showed the Figure 5-5 explains the growth of the deployment. As the first observation suggests, it is the level of profitability gained by investors and developers that mainly influences the deployment of PV projects. The economies of scale of PV installations helps in reducing the overall cost of PV projects and consequently increases the profit levels (illustrated in reinforcing loop R1). The project cost, in turn, reduces the generation cost (known as the Levelized Cost of Electricity Generation or LCOE) and consequently the feed in tariff price. The tariff rate is adjusted discretely (in steps) after a certain delay, called the qualifying period. The price adjustment is determined by the generation cost and predefined internal rate of return (IRR[9]). Price adjustment loop B1 helps to correct the incentive level to make sure that the deployment levels are as intended by the policymakers. Nevertheless, the delay in systems usually creates fluctuations (J. Sterman, 2000).

Given the market growth loop, we can assume that the cost will show a declining trend (with some fluctuation resulting from market forces). This allows more profit gains for investors and developers. Consequently, the period of each price adjustment (usually a reduction) will provide an opportunity to lock-in a higher level of profitability. The profit-to-supply relationship developed by (Grau, 2014b) can be used to represent the inflow of stock for intended projects. These projects, however, are realized depending on the construction time or project completion time decided by the developers. This gives us reason to explore the decisions made by developers in more detail.

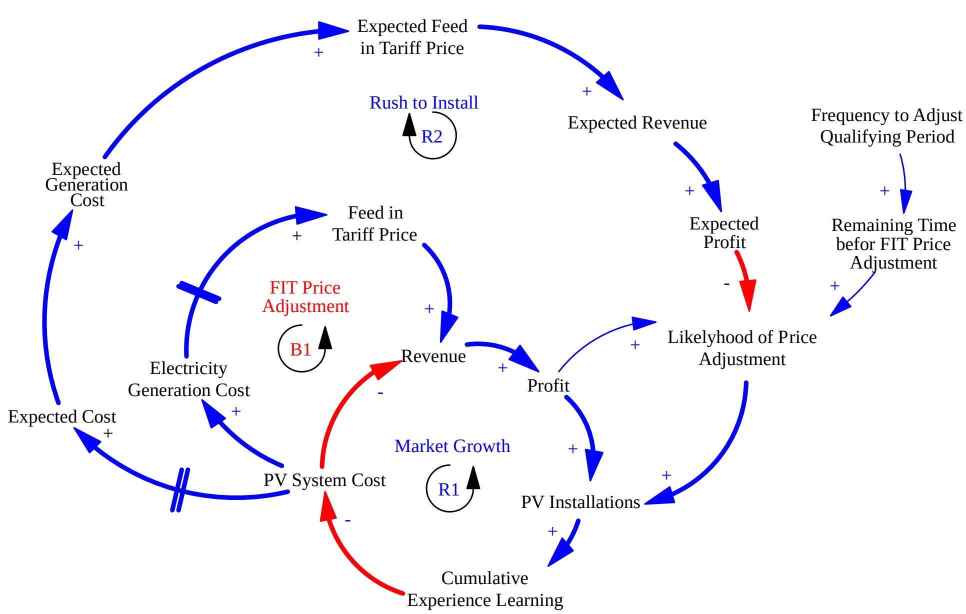


Figure 5-5: Model causal loop diagram

Source: Author diagram

[9] The IRR percentage in this model is estimated from historical data.

The project completion time is defined using the following relationship. Throughout the qualifying period, the project completion time is assumed to be the average (7 weeks); however, when the period remaining before the price-adjustment deadline (Figure 5-6 right), becomes less than seven weeks, the completion time is adjusted to the maximum possible. The policy term or the qualified period could be used to set a timeframe for projects. That is, the duration of a policy term (Figure 5-6 left), provides an indicator or a deadline for project developers. Hence, the variable “remaining time before the deadline” was devised to estimate how project developers plan their project schedules. When the remaining time before the deadline is < 7 weeks, project completion can range from 3 to 7 weeks, using the relationship defined in Figure 5-7. This relationship, however, is not sufficient to explain the non-linear behaviour of weekly installations. The rush-to-install effect discussed above can be modelled using the developer expectation of cost and project profitability. Unlike fixed or discrete feed in tariff price schedules, estimation of continuous feed in tariff prices could provide an updated indicator of the likelihood of price changes.

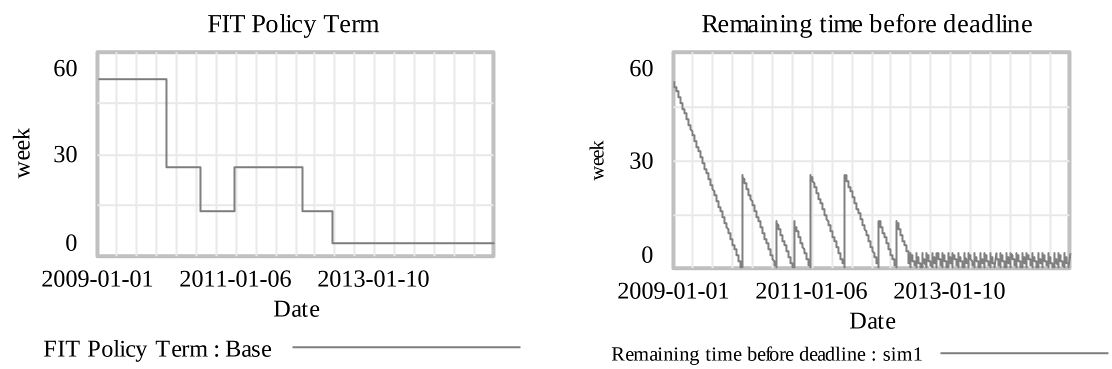


Figure 5-6: Model parameters to simulate discrete adjustments

Source: Author simulations

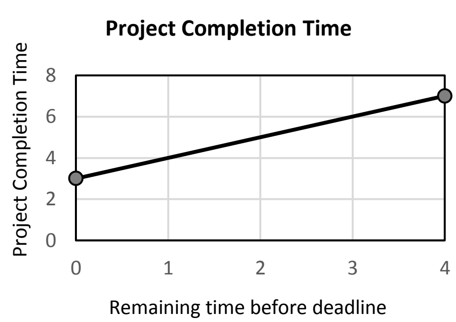


Figure 5-7: Project completion time

Source: Author simulations

The likelihood indicator influences the developers to speed their project construction if profits are expected to decline in the future and vice versa. The likelihood can be represented as:

$$L = \frac{\pi}{\pi'}$$

Where L is the likelihood indicator, π is the project profit, and π' is the expected profit. Using the likelihood indicator, the developers form their expectations from the trend of profits shown in loop R2, in the causal loop diagram.

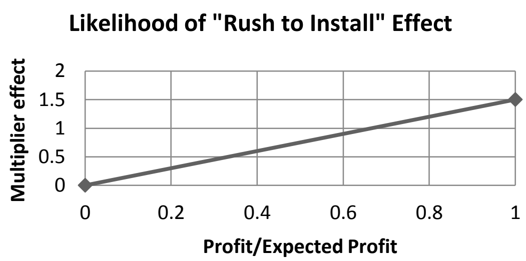


Figure 5-8: Rush-to-install effect

Source: Author simulations

As the pattern shows, developer decision-making is influenced by time. Therefore, the probability multiplier impact is marginal except in the third quarter of the qualifying period. For this reason, a corrective non-linear relationship is necessary. The following relationship in Figure 5-9 below shows the effect of the time remaining before the price adjustment, on the probability multiplier. This relationship is formulated as:

$$e = L(R)$$

Where e is the effect of remaining time on the decision for project deployment, and R is the ratio of remaining time. R is defined as:

$$R = \frac{t_R}{q_D}$$

Where t_R is remaining time before the qualified period deadline, and q_D is the qualified period duration.

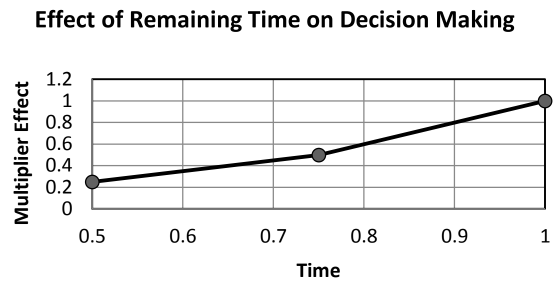


Figure 5-9: Effect of remaining time to complete projects

Source: Author simulations

The interaction between these variables is explained in the stock-flow diagram below. Note that the stock for the simulated installations of PV project is disaggregated into three stocks, because its pattern matches a second-order material delay. The stock called "Installation before Connection" refers to PV installations made by project developers before the panels are connected to the electric grid. This stock will be used to analyse the PV installation pattern.

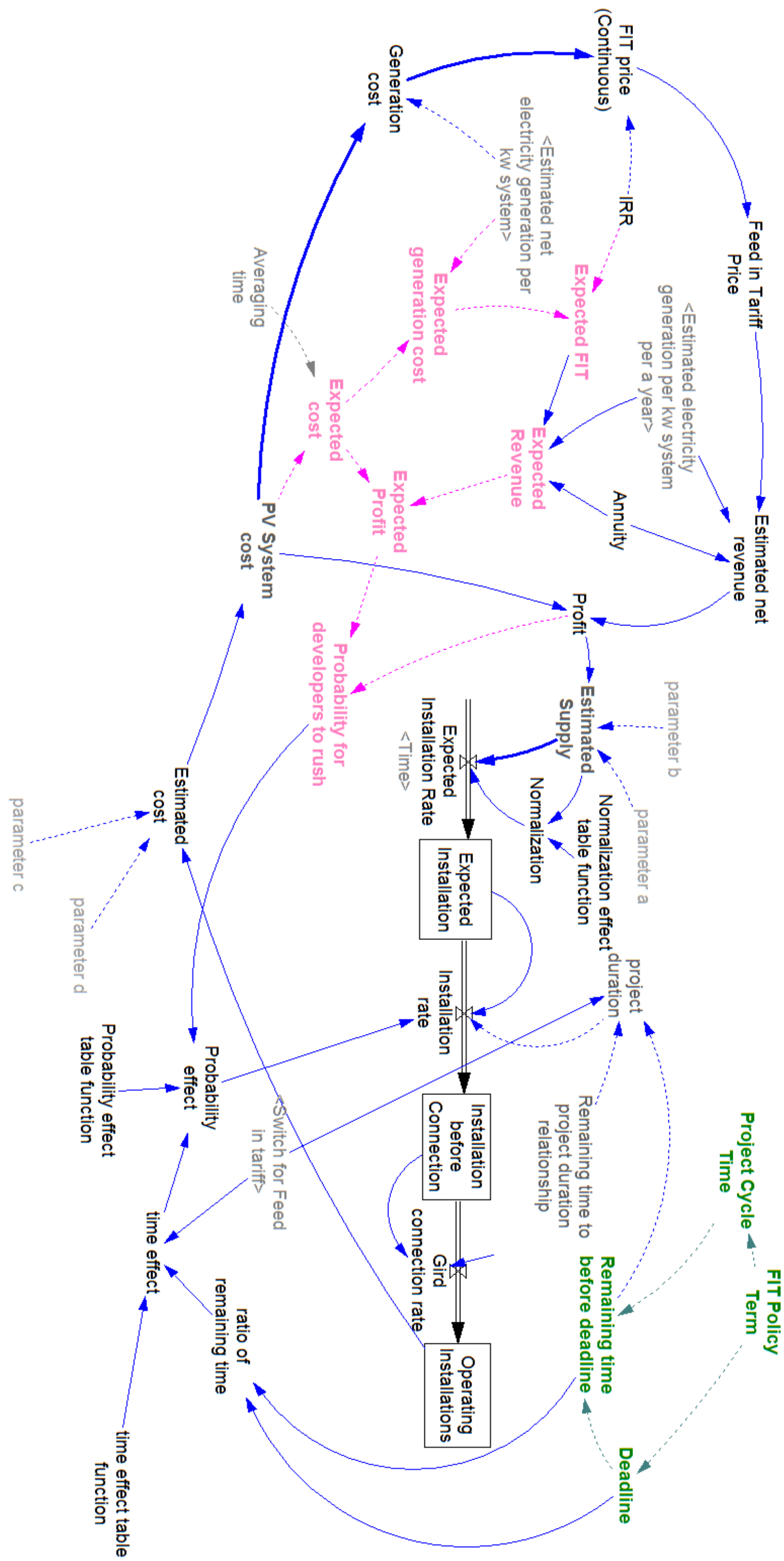
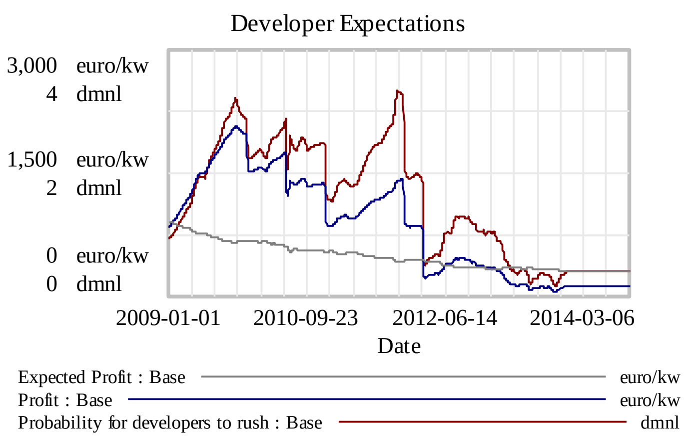


Figure 5-10: Stock-flow diagram for the dynamic tariff price adjustment

5.4 Model Results

Using the incremental developers' expectation about cost and profit to form their decision-making process, the model succeeded in replicating not only historical data but also the historical pattern and the logic behind it. This provides a viable alternative to the optimization technique used by (Grau, 2014b). The (Figure 5-11 top) shows the expected profit, which was developed from the parallel structure introduced in loop R2, and shows how it influences the likelihood of the rush-to-install effect (Figure 5-11 bottoms).



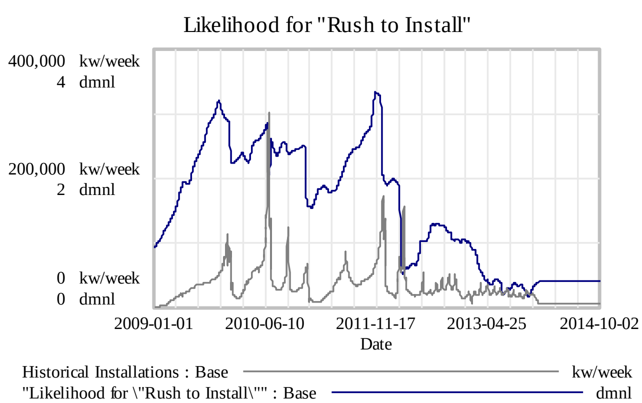


Figure 5-11: Project developer expectations and the likelihood of accelerated deployment

Source: Author simulations

Using the understanding developed in the basic structure, the simulation results could replicate the installation pattern. The effect on installation pattern is shown in Figure 5-12.

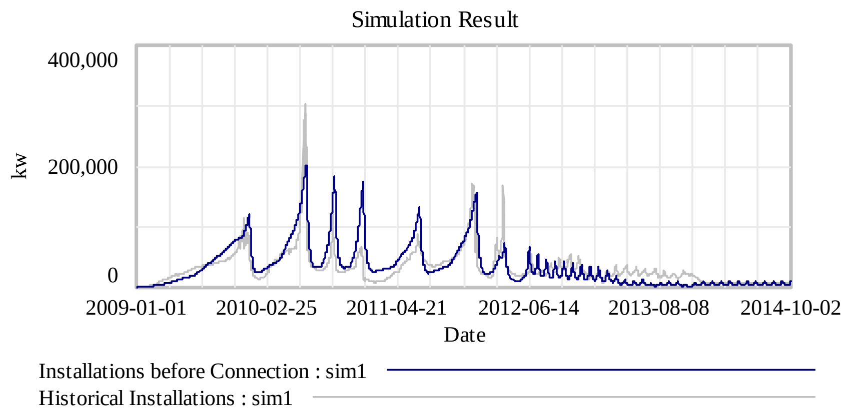


Figure 5-12: Model results

5.5 Discrete Feed in Tariff Policy

The PV system cost is a contributing variable to the design of the feed in tariff policy. In order to see the impact of PV-system cost changes, the changes have to be tested against responsive feed in tariff policy. Because the historical feed in tariff price data will not provide accurate results, the discrete model of the feed in tariff price adjustments was developed for this purpose. Due to the complexity of the feed in tariff pricing policy, a simpler model was devised for testing. The discrete model offers relatively accurate tracking of the historical data.

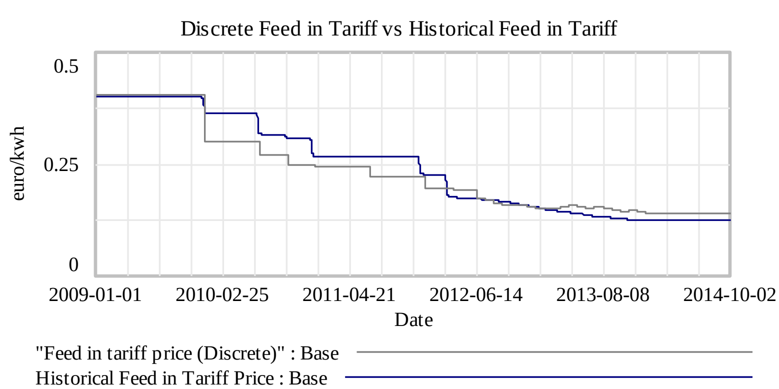


Figure 5-13: Feed in tariff comparison

Source: Author simulations

5.6 Testing and Analysis for the Discrete (Stepped) Model

The model was tested using partial tests to verify its intended rationality. Specifically, the model was tested to examine its response to unexpected changes in system cost. This was modelled using the STEP function for the period between the 70th and 130th weeks. The results show reasonable behaviour; the expected profits increased when the cost increased and vice versa. This is because the R2 loop of developer expectation dominates the system in which the feed in tariff prices are adjusted accordingly to create a profitable margin. Moreover, the developer expectations are derived from an exponential averaging of PV-system cost. In addition, the model was tested against extreme values. Testing the model with large values of unexpected cost increases may lead to negative profits and consequently negative numbers of installations. However, a normalization relationship is introduced to correct this issue. The simulation of the discrete policy provided excellent results similar to the historical pattern. However, to produce an efficient policy, the pattern has to be more stable against fluctuations.

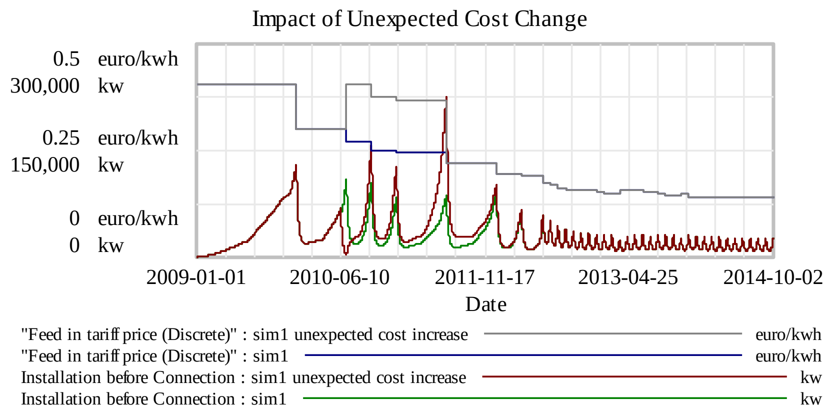


Figure 5-14: Impact of Unexpected Cost Change

Source: Author simulations

5.7 Continuous (Smooth) Feed in Tariff Policy

The continuous feed in tariff policy assumes no deadlines for price adjustments. Similar to electricity prices, the tariff prices can be determined depending on the updated cost of PV systems. This allows the policy to remove a critical delay that causes fluctuations of PV deployment. Moreover, based on this assumption, as there are no deadlines, the majority of projects will have a completion time around the average (7 weeks), and there will be no need to shrink this period. Consequently, there will be no effect from the time remaining before the deadline, which is a major non-linearity in the discrete model that reinforces the deployment rate.

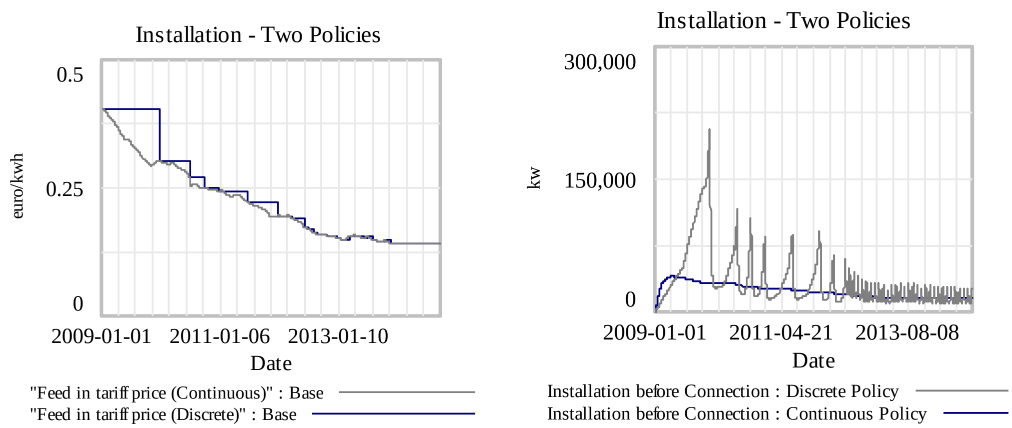


Figure 5-15: Effects of two policies

Source: Author simulations

The results show that the continuous policy is more robust and stable to change. (Figure 5-16 left) shows a STEP test of the cost increase of 50% between the 70th and 130th weeks. The developer expectation stabilized in the case of continuous price adjustments (Figure 5-16 right). The probability to rush became marginal because the model eliminated the effect of remaining time.

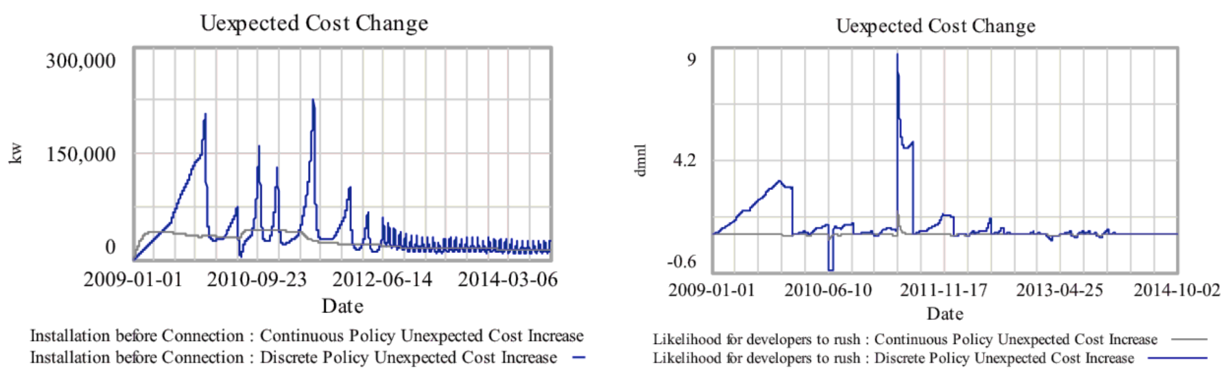


Figure 5-16: Unexpected cost change on PV installations

Source: Author simulations

5.8 Comparison of Continuous and Discrete Policy

When comparing the results of the two policies, it is clear that the continuous policy could substantially reduce policy costs. The policy budget to be realized by the end of the 2015 policy term (i.e. after 20 years) would end in 2035. The discrete feed in tariff policy could allow faster introduction of solar energy in cases with fluctuating patterns because such growth is highly motivated by profit and unpredictable market conditions. Whereas the continuous policy offers a slower but more reliable pattern, that prioritizes cost efficiency rather than the speed of renewable energy deployment. According to the model results, the discrete policy could achieve an operating capacity of 10 GW by October 2014, at a policy cost of ~ 5 T EUR, while the continuous policy could achieve 7 GW over the same interval at half the cost.

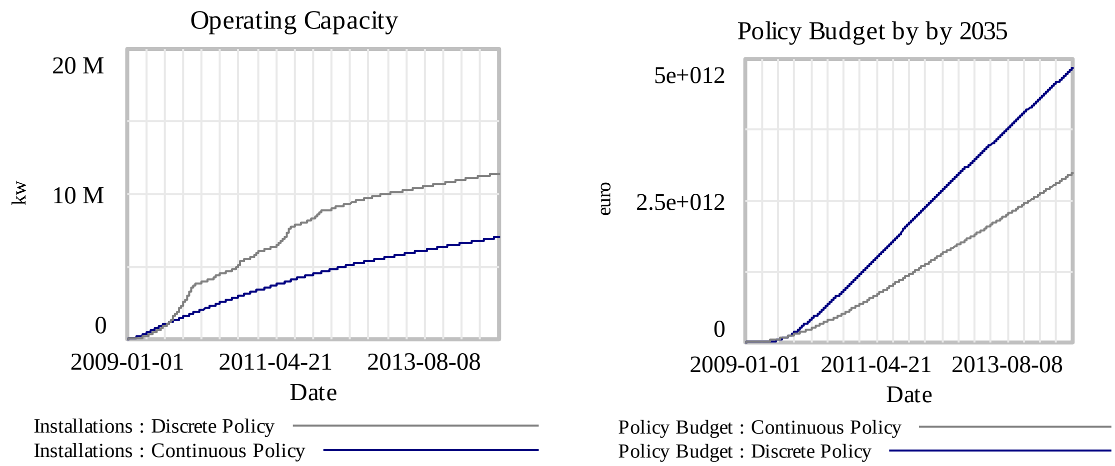


Figure 5-17: Policy budget comparison

Source: Author simulations

5.9 Summary and Conclusions

Here, was discussed the influence of feed in tariff policy on the development of rooftop PV in Germany. Feedback loop analysis was used to identify issues incorporated in the discrete-based feed in tariff policy. We found that time delays and nonlinearities were a major cause of the cyclic fluctuations in the development trend of PV deployments. The system dynamics model developed in this paper was capable of closely tracking the historical pattern, which allowed comparisons of the discrete and continuous versions of FIT policy. The model showed how continuous price adjustments could improve market growth while maintaining control over the policy budget.

6 Electric Grid Capacity Planning for Renewable Energy Development in Japan

Overview

In this chapter, the author develops a system dynamics model for the feed in tariff policy that takes into consideration the development pace of renewable energy. This is to make the pace of development accord with the available infrastructure needed to accommodate it, or more specifically, the electricity transmission network. Planning upgrades of the transmission network capacity have become an increasingly important issue in developed countries that have implemented a policy for renewable energy diffusion, and Japan is no exception. The recent energy challenges induced by the Fukushima earthquakes resulted in a series of important energy policies intended to speed recovery from the energy shortages caused by the shutdown of the nuclear reactors and still reduce carbon emissions. This required setting high goals for energy efficiency and conservation, as well as ambitious targets for renewable energy installed capacity. Despite the ambitious targets, renewable energy development in Japan faces some challenges due to grid capacity limitations. These come from the centralized structure of the electricity network, which is incompatible with a large and varied supply of renewable energy. Because of that, grid connection requests from renewable energy developers has been suspended by many electric utilities for a prolonged period, resulting in a constricted market delayed in achieving a green future. This chapter provides a background for the development of the grid structure in Japan. The system dynamics model developed in this chapter was used to compare grid expansion alternatives and to estimate the possibility of achieving the renewable energy targets of 2020 and beyond. Analysis is provided to explain development behaviour and an estimate attempted of long-term grid capacity expansion in the case of reduced conventional energy.

6.1 Introduction

Since the Fukushima incident in March 2011, securing a stable supply of energy has been one of the primary goals of the Japanese government, complicated by public calls for shutting down all nuclear reactors. Considering the fact that Japan has limited domestic energy resources that constitute less than 9% of the country's total primary energy consumption, it is important to consider alternative sources of energy that could increase the chances for energy self-sufficiency. According to 2013 statistics, Japan is the largest natural gas importer, second largest importer of coal and third largest consumer (and a net importer) of oil. The Fukushima 9.0 magnitude earthquake in March 2011 resulted in an immediate shutdown of 10 GW of nuclear generating capacity. Due to safety measures, all other plants were gradually shut down for inspection and maintenance, which resulted in a loss of more than 25% of Japanese power generation, and which represented the least cost energy resources. This energy was substituted for more expensive fossil fuels, like natural gas, crude oil, and coal, which in turn led to higher electricity prices for consumers, higher government debt, and loss of revenue by electric utilities (METI, 2014a, 2014d). Japan spent about 270 billion dollars or roughly 60% more on fossil fuel imports than usual, between 2011 and 2014. Moreover, this coincided with yen depreciation and unprecedented high oil and natural gas prices, which were greatly impacted by the political instability in the Middle East (later called the Arab spring). Oil prices steadily increased after the nuclear incident from 40 USD/barrel in 2011 to over 60 USD/barrel in 2014. At the same time, LNG increased from above 10 USD/MMBTU (1 MMBTU is equivalent 1 million BTU "British Thermal Unit" or 28.26 m^3) in 2011 to 17 USD/MMBTU in 2014 (METI, 2014c). Consequently, Japan faced a trade balance down from a 30-year surplus of 65 billion USD in 2010 to a trade deficit of 112 billion USD in 2013 (Demetriou, 2014; Kurtenbach, 2014).

The increase in fossil fuel imports and consumption resulted in increasing carbon emissions to new records. The Japanese Ministry of Environment published that the recent records of carbon emission reached > 1.39 billion tons in 2013 compared to 1.28 billion tons in 2010, an increase of about 8.5%, since the Fukushima earthquake (MoE, 2015). To counter this problem, many policies were devised to increase the fossil fuel consumption efficiency rates, as well conservation measures. The increase in the tax implemented had positive effects on lowering fossil fuel consumption (EIA, 2015a). In addition, the renewable energy subsidies, in addition to the feed in tariff policy, were intended to substantially increase the role of RE in the energy mix.

The innovative energy strategy suggested three scenarios for the transition towards a new energy mix in which nuclear power was reduced to 0%, 15%, or 20–25% by 2030. In these three scenarios, the average share of renewable energy is supposed to be 63 GW, out of which utility-scale solar would make up 23 GW, and wind energy around 34 GW (NPU, 2011). While the innovative strategy scenarios suggest around 63 GW of wind and solar, the 4th basic energy plan, announced in early 2015, indicated a target of 20% of the overall energy mix by 2020 (METI, 2014e). In addition, the industry associations explicitly aimed for 65.3 GW for solar (JPEA, 2014) and above 10 GW for wind by 2020 (JWPA, 2014). In order to inject this new energy supply into current operations, an equivalent increase in the capacity of the electric grid and transmission network was required. The capacity increase to the electric grid offered by the electric utilities was 5.6 GW, an order of magnitude below what is required (JREF, 2012b).

Due to the shortage of available electric grid capacity, five of the ten private electric utilities have suspended accepting grid connection requests for all large-scale renewable energy projects. This has contracted the development of renewables (JREF, 2014; Watanabe & Urabe, 2014). For example, the number of applications approved by the Ministry of Industry, Trade and Economy (METI) for solar energy projects has reached ~ 70 GW while only about 15% has actually been constructed (refer to Figure 6-1) (METI, 2014f; Movellan, 2014). In a survey conducted by the Japan Renewable Energy Foundation in 2013, investigating the reasons for delay of those projects, around 70% of the respondent explained that interconnection issues are the major reason for the delay in the development of projects, if not altogether abandonment (JREF, 2014). Construction of the grid constitutes a challenge because this kind of construction takes a relatively long time (5–10 years). Compare this with projects for renewable energy: 1–2 years for solar energy and 2–3 years for wind energy (Kuwahata, 2013; METI, 2012). These differences in construction times puts under question whether the planned capacities in any of the three scenarios could be achieved by the dates expected. The delay in constructing the expansion of the grid will retard the development of renewable energy. This will also slow the trend of falling cost in the technology for renewables (Sawyer, 2015). Consequently, consumers will continue to bear the burden of the FIT policy cost so long as electricity prices remain high. In fact, the retail electricity price for consumers in Tokyo area has increased by 37%, from ~ 6500 JPY in March 2011 to 8500 JPY in July 2014 (METI, 2014c). Moreover, under these conditions, renewable energy policy will be less effective. Research shows that grid enhancement can quadruple the potential of wind energy if the interconnection between the regions is sufficiently enhanced (Shibata, 2014). The pattern of reservation shows sudden growth in February 2013 and February 2014, just before the end of the feed in tariff term. Because developers expected a new price reduction at the beginning of Japanese fiscal year starting in April, many rushed to apply for grid connections to avoid the lower tariff prices. The same pattern happened in Germany but with higher frequency due to the frequent tariff changes. The problem is referred to as the "rush-to-install effect" and discussed by (Grau, 2014b) in detail. In Chapter 4, the author discussed the problem using a system dynamics model.

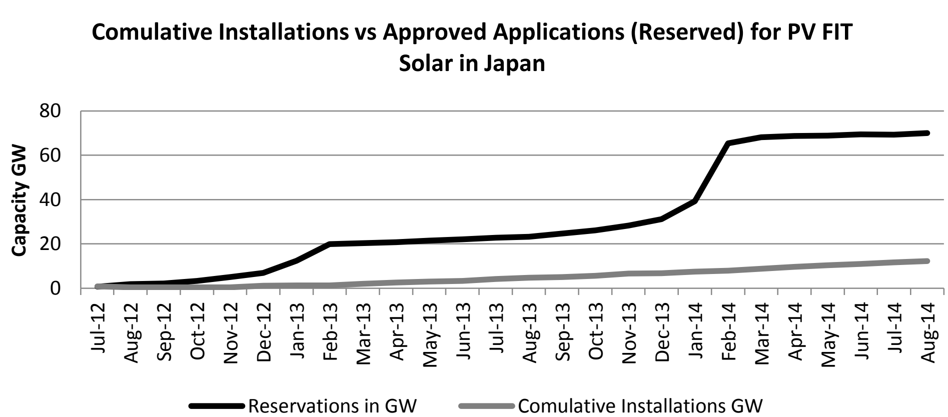


Figure 6-1: Approved applications by METI vs. actual installations of solar (PV)

Source: (METI, 2014f)

6.2 The Electric Grid in Japan

There are ten major private electric utilities in Japan. Each of these utility companies manages the demand and supply of its region. The interconnection between regions is administered and negotiated by the concerned utilities. Because the current arrangements with conventional energy generate an extremely stable supply of electricity, the interconnection capacities have been kept marginal, only to be used to supply utilities in urgent demand. The earthquake in Niigata in 2007 unveiled the weakness of the electric transmission network in supporting Tohoku Electric utility when the power from 7 nuclear reactors and 13 thermal plants was disrupted. Later in 2011, the Great East Japan Earthquake demonstrated the significance of the difference in the power frequencies in east and west Japan (METI, 2012).

6.2.1 Development of Electric Utilities in Japan

Tokyo Electric Lighting was the first and only electric power company in Japan when it started operation in 1886. Ten years later, 33 utilities had been established throughout Japan. Between the 1890s and World War I, there were more than 700 utilities operating due to modernization and economic development in the country. After the first world war, this large number of utilizes was consolidated to form just five utilities. During World War II, the utilities were integrated into a state-owned utility called, Nihon Hatsusouden (日本発送電) with nine distribution companies. In 1950, the Electricity Reorganization Order was mandated to divide the country into nine regions starting from May 1951 (Okinawa was included after 1972). This marked the birth of the regional monopolies of vertically integrated utilities operating today (H. Asano & Goto, 2013).

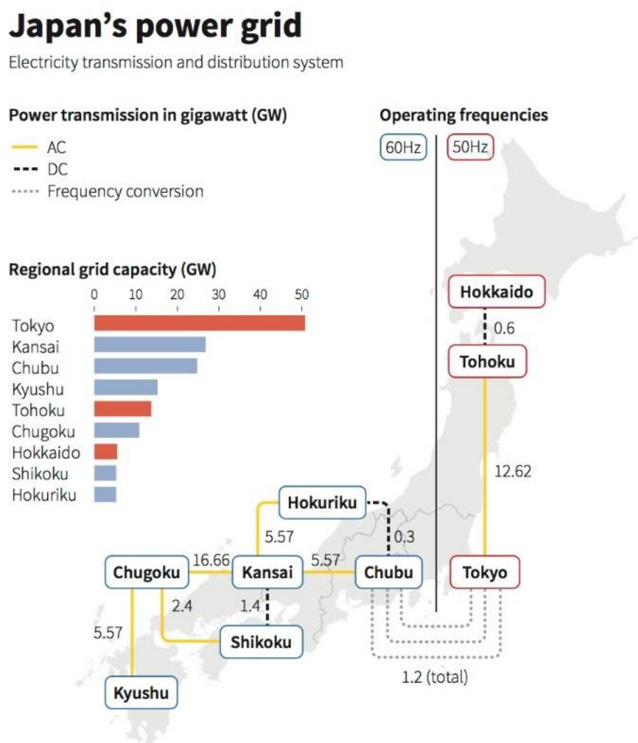


Figure 6-2: Power grid structure in Japan

Source: (Reuters, 2014)

Due to the legacy structure of the electrical system in Japan, two frequencies are used in Japan: 60 Hz in the west and 50 Hz in the east. To resolve the compatibility issue, three frequency-conversion stations were developed to convert the electrical frequency for use between regions. Technical limitations of these frequency converters introduce another bottleneck in the transmission of electricity supply between the east and west of Japan. In addition to the frequency converters, some regions are interconnected using a high voltage direct current (or HVDC) interconnection. HVDC interconnection provides a transmission solution that minimizes the loss of electricity transferred between regions over short distances. However, this technology has a limited capacity and hence introduces yet another bottleneck to longer distance transmission of electricity in Japan. For example, Hokkaido is known for inexpensive, vast, flat landscapes that are very suitable for utility-scale solar power plants. Many investors have indicated that future plans for solar energy are not feasible without the inclusion of Hokkaido (Asahi Shinbun, 2013). Moreover, the largest share of potential wind energy is also located in Hokkaido, as well as in the northern areas of Tohoku. Since the beginning of the feed in tariff policy in July 2012, many investors have competed to develop their projects in Hokkaido.

Table 6-1: Wind power plant interconnection standards in Japan

Regulator	Year	
Ministry of Economy Trade and Industry	2004	Guidelines for technical requirements for system interconnection for maintaining power quality
Japan Electric Association	2010	Grid interconnection code
Ministry of Economy Trade and Industry	2009	Ministerial ordinance setting technical standards concerning wind power generation facilities
Japan Electric Association	2001	Wind turbine generator code

Source: (IEC, 2012)

By May 2013, more than 80 applications with an equivalent power capacity of 1.5 GW were approved by METI while the electric utility in Hokkaido, Hokkaido Electric (HEPCO), announced that it can only accept 0.4 GW and that the remainder will be cancelled (ECN, 2013). This is because Hokkaido Island has a relatively small population and consequently low power demand. Therefore, the electric power generated from renewable energy exceeding the regional demand must be transferred to Honshu Island. However, the capacity of the HVDC connection between Hokkaido and Honshu islands is currently limited to 0.6 GW. Moreover, the power transferable from west to eastern Japan through the frequency converting stations is limited to 1.2 GW. Given the geographic dispersion of natural resources in the northern and southern areas in Japan, the limitations of the electric transmission network restrict the transferability and exchange between regions, of electricity that could be generated by renewable energy. The same scenario recurred, involving four other utility companies including Tokyo Electric Power Company (TEPCO) and Kyushu Electric Power Company (KYUDEN), which are the largest utilities in Japan (Watanabe and Urabe 2014).

The private electric utilities indicated in the hearings at METI committee meetings that there are several obstacles for renewable energy introduction in Japan due to the existing legacy structure of the electricity system. However, other countries in Europe, as well as in North and South America, have similar grid structures but still have introduced higher targets of renewable energy development.

6.3 Problem Analysis

The blackout and power shortages after the Fukushima accident, and inability to share the electricity between east and west Japan have put public attention on the transmission network design and inefficiencies. Moreover, the debate about accelerating renewable energy deployment being limited by transmission capacity and the concerns raised about transmission network reliability was unacceptable to renewable energy enthusiasts and environmentalists in Japan. However, meeting the increasing demand from renewable energy developers by expanding transmission is difficult in structured markets because of economic and reliability assessments.

The legacy structure of the electric system imposes some challenges to the energy transition intended to decarbonize the energy mix. Moreover, nuclear safety issues cause even more difficulties for policy makers. The renewable energy transition is a common trend around the world that does pay off its investment. The delay in meeting renewable energy targets in Japan will have significant economic and environmental impacts. These effects are summarized in the following causal loop diagram CLD. In order to estimate the benefits of the accelerated trend of renewable energy development, a system dynamics model was developed. The model was used to verify the business-as-usual scenario of grid expansion and a scenario where conventional energy is replaced with renewable energy.

The initial goal of electric power transmission lines was to link remote power plants to load centres. Transmission expansion is justified wherever there is a need to connect least cost generation to meet the growing load demand. Expansion planning has always been a complicated task, and it is very different depending on the electricity market structure (regulated versus deregulated) and on the energy mix to be connected. In structured electricity markets, transmission expansion planning is carried out by vertically integrated utilities that are responsible for the generation, transmission, and distribution of electricity. Utilities perform studies to forecast the load demand and plan transmission expansions accordingly. Because conventional power plants incur larger costs than transmission expansion does, transmission planning is always focused on selecting the least-cost power generation alternatives to maximize return on investments. In general, the planning is conducted in a sequential process starting with generation planning, to selecting the generation technology, and finally, to the transmission planning. The reliability is another important concern that has to be met to justify transmission expansion. This is why transmission planning is usually formulated as an optimization problem with an objective function that minimizes the cost, with reliability as a constraint (Wu, Zheng, & Wen, 2006).

The essence of deregulated electricity markets is increased competition and prevention of market monopolies. Deregulated markets impose separation on aspects of electricity businesses (i.e.

generation, transmission, and planning), and encourage the participation of different players to compete in providing services and thereby to lower costs. The generation companies, unlike in an integrated utility, have different and sometimes conflicting goals and objectives. The diversity of power generation companies in unregulated markets invalidates many assumptions common in regulated markets and requires fundamental changes in the transmission expansion planning process. It also requires that all stakeholders should coordinate and define new (common) planning objectives; for example, upon what criteria the transmission planning should be performed, especially since the least-cost criteria is no longer feasible. Should the criteria include social interests (social welfare)? How should private and public interests be balanced?

Renewable energy generation, wind and solar energies, in particular, imposes challenges that are significantly different in regulated and deregulated markets. The upfront costs of wind and solar power generation facilities are usually much less than for an expansion of the transmission capacity. This is because wind and solar resources are distributed across wide geographical regions and the best locations for generation are often furthest from the load demand centres. Whereas, conventional power plants have much more flexibility in locating. Second, in regulated markets, because transmission expansion takes much longer to build, it usually takes place before generation power plants are planned and constructed. Moreover, renewable energy projects from wind and solar, especially when accelerated under promotion policies, have much shorter development time. Solar PV projects might take up to two years, and wind energy projects up to four years, due to differences in the application, construction, and grid permitting processes used for each technology). Therefore, additional measures must be taken, in addition to the expansion of the transmission capacity.

In deregulated markets, transmission planning occurs in two categories: transmission planning and transmission investment. Transmission planning refers to the technical assessment of the electric system reliability as well as the requirements imposed by economic and environmental stakeholders. Transmission planning is assigned a single entity or what is called the independent system operator (ISO) to perform the centralized planning. Transmission investment category includes analysis of transmission expansion projects and assessment of their financial variability. Compared with other markets, Japan has taken a cautious and gradual approach to electricity market reforms, and is considered to have started rather late. In Japan, electricity market reforms were mandated in April 2005 and initiated the establishment of two organizations: The Electric Power System Council of Japan (or ESCJ) and the Japan Electric Power Exchange (JPEX). METI has emphasized the role of nuclear energy to support the perspective of energy security and climate mitigation. The long term plan was to add 14 GW of nuclear energy to the energy mix by 2014 (Goto & Yajima, 2006)

6.3.1 The Electric Grid Network in Europe

The electric grid capacity issue is not special to Japan but also has occurred in various countries with developed electric grid systems like Western European countries and countries in the Nordic region. In Germany for example, which is taken as the role model of renewable energy development, the electric grid bottleneck took place shortly after the implementation of the EEG policy (alternatively known as FIT policy). In 2002, the German government set a strategy of non-binding targets for wind deployment: 0.5 GW by 2006, 2–3 GW by 2010, and about 25 GW by 2030 (KPMG, 2010). However, only about 100 MW had been installed by 2010. In the EEG 2009 amendments, serious measures were taken to ensure increased deployment levels to 10 GW by 2020, and 25GW by 2030 (Anzinger & Kostka, 2015). Later in 2011, the wind deployments reached a plateau when the electric grid capacity limit was reached, and further grid capacity expansion was necessary. Amid this debate, banks and investors refused to finance projects unless grid connection was assured, resulting in an egg-hen dilemma (Anzinger & Kostka, 2015). Restructuring the electricity markets with the unbundling process, separates the planning of generation and transmission capacities and requires the same collaboration and coordination that existed in the centralized electricity market. In a restructured market, the entities might focus only on their economic benefits rather the overall mission of providing stable and reliable electricity (IEC, 2012; W. Li, 2011). Therefore, a case where the power generator might over-produce the supply of power to exceed the peak load, or the grid capacity, would be possible. This is especially true when power generation is highly incentivized, as is the case under the feed in tariff policy. The distributed nature of the renewable energy supply makes it difficult to coordinate grid capacity planning and investment. Policies promoting renewable energy may not coincide with, and in fact, may outpace transmission planning and development. Such challenges were present in both Germany and Japan (Ebinger et al., 2014).

The electric grid system in Germany was completely unbundled by 2005. The grid system is owned, operated, and maintained by four transmission system operators (TSOs) in their respective regions, who administer the EEG feed in tariff. The Federal Network Agency for Electricity, Gas, Telecommunications, Post, and Railway (Bundesnetzagentur or BNetza) regulates the national grid and ensures its accessibility to all of the market (BNetzA, 2013). (ENTOS-E, 2014) The 10-year network development plan for 2014 (abbreviated TYNDP 2014) concluded that renewable energy development is a major driver for grid development until 2030. The average network growth will be about 1% per year of the existing capacity, to keep up with the energy-generation-capacity increase of about 3% to 5% per year. One-hundred potential bottlenecks have been pinpointed across the European grid if no further enhancement or development is implemented. Consequently, the grid interconnection capacity must double throughout Europe by 2030. This plan is estimated to cost about 150 billion euros out of which 50 billion would be for subsea transmission cables. The cost of the plan would be about 1–2 EUR/MWh to electricity consumers (i.e. roughly 1% of an average electricity bill). Despite the substantial estimated costs of this plan, it has significant benefits to the electricity consumers in all the European countries participating in it. Enhancing Pan-European grid integration could level electricity prices across these countries to around 2–5 EUR/MWh. The plan would also allow tremendous savings by utilizing now wasted solar and wind energy estimated to be between 30 and 100 TWh. This would have a critical effect on electricity prices. From another aspect, the retention of renewable energy excess will be essential to the energy transition strategy. In addition, the expansion plan has indirect environmental benefits. The TYNDP 2014 project portfolio could decrease GHG emissions by 20% in 2030. The investment would implement cutting-edge technologies that could keep the European grid at the forefront of technological advancement and technical leadership.

The electric grid development in the Nordic region has shown another good case study to be investigated where the huge investment has been placed for cross-border connectivity to allow regional trading and cooperation in the electricity sector. The cross-border transmission grid investment in the Nordic countries are lagging behind their intended schedule (Makkonen et al., 2015). Actually, according to the Ten Year Network Development Plan (TYNDP) about 40% of the integration plan is either delayed or cancelled due to social resistance, and processing permits have taken longer than initially expected. In some cases, overhead power lines have been replaced by underground cables. The plan aims to increase the network capacity to accommodate a variable renewable energy supply of 125 GW or about 80% of the expansion capacity, yet this expansion appeared to be just half of the expected renewable capacity. This has resulted in delaying the network capacity investments for two years (ENTSO-E, 2012). For example, in 2014, the electricity transmission system operator in Sweden, Svenska Kraftnät, faced a situation where the number of wind power applications submitted for grid connection exceeded the peak demand in Sweden by 140%, which was impossible to realize (Makkonen et al., 2015).

Grid expansion, on the other hand, may incur significant costs, which is one of the main reasons for resisting its expansion decision and hence delaying its development further. However, (Nabe, 2013) found that grid expansion is actually the least expensive way for large supplies of renewable energy to be integrated with the grid offering far more benefits and costs savings in the long term. Moreover, (Nabe, 2013) found that although grid expansion might cause a substantial delay in renewable energy deployment, this delay should not be considered a legitimate excuse to slow down renewable energy deployment. Rather, grid limitation should guide renewable energy developers to focus their efforts on distributing their projects for other renewable energy sources.

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6.4 Grid Capacity Planning

Electric grid planning (or electric transmission capacity planning) is a classical problem in power engineering. The planning seeks to optimize expansion to meet technical, economic, and environmental objectives while minimizing cost. Depending on the time horizon of the problem, details of the modelling process increase proportionally. The market structure also changes the objective function of the modelling process. In the case of structured or regulated markets, the objective function is to minimize the cost of investments, while in deregulated markets, the objective function is to meet a set of goals, such as maximizing financial profitability, social welfare, or others (Baldick & Kahn, 1993; Buygi, Balzer, Shanechi, & Shahidehpour, 2004). This complexity of modelling and planning the transmission system require the separation of short, medium, and long-term planning, depending on the level of abstraction desired. Long-term models have a time horizon of 20 years, and they are used as a simplified solution for next stage planning. In contrast, short-term planning requires extensive details and a large number of parameters and computation to decrease the level of uncertainty (Sousa & Asada, 2015). There are several modelling techniques and methods that are appropriate to transmission network planning, including linear programming, dynamic programming, mixed integer programming, and system dynamics (Orfanos, Georgilakis, and Hatziargyriou 2013; Ojeda, Olsina, and Garcés 2009)

6.4.1 The Model

In order to verify the policy objectives to reach certain capacity goals and to estimate the required renewable energy supply to be developed in the long term, a system dynamics model was developed. The model captures the process of renewable energy development as well as the electric grid expansion process. The renewable energy development process starts with filing an application to METI for approval. Application approved by METI is then submitted to the utilities to obtain grid connection permits. The approval from METI and grid connection permit both require a standard processing time of two months each. Unlike solar and wind, the standard processing time for biomass energy applications and grid connection permits is three months. In addition, the processing time differs depending on the number of applications, as well as the resources available to process them (METI, 2015). The difference in development speed between the grid expansion and renewable energy sources, results in a backlog of renewable energy (RE) applications. Applications might be cancelled or abandoned after waiting for a prolonged period. The model assumes a period of 18 months before cancelling the application. Figure 6-3 shows the process illustrated in stock-flow notations.

The model was developed using a system dynamics structure called "goal seeking", for both the renewable energy capacity and grid capacity. The goal-seeking structure is shown in Figure 6-3 below. The variables of the model are defined mathematically using the following functions:

$$S = \int_{t_0}^{t_n} \Delta S + S_0$$

and

$$\Delta S = \frac{S_G - S}{T_{adj}}$$

where S is the capacity level in the stock, ΔS is the change in the sock, S_0 is the initial level in the stock, S_G is the goal or target level of the stock and T_{adj} is the average of the adjustment time for the stock level. In addition, t_0 and t_n represent the beginning and end of the period of analysis. Using this formulation, the rate of renewable energy supply was calculated based on the difference between the existing level of stocks and the target capacity, or goal.

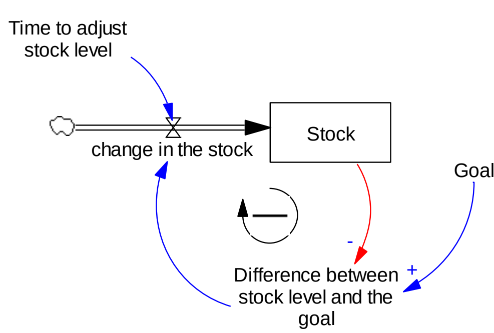

Figure 6-3: Basic model of a system dynamics goal-seeking structure

Source: Author's drawing adapted from (J. D. Sterman, 2000)

To illustrate the output of the basic goal-seeking model, assume the following values: $Stock = 0$ (units), Goal = 50 (units), and Time to adjust stock level = 5 (time units). The simulation result of this structure produced the following pattern in Figure 6-4.

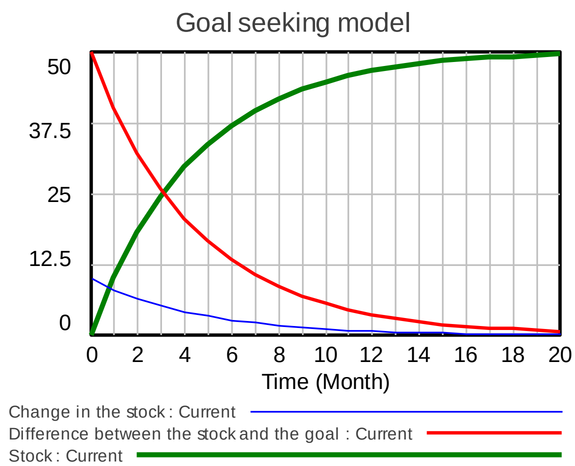

Figure 6-4: Simulation results from the fundamental goal-seeking model

Source: Author's drawing

The results suggest that the target can be achieved in 20 time-units. The following structure was developed based on the goal-seeking structure.

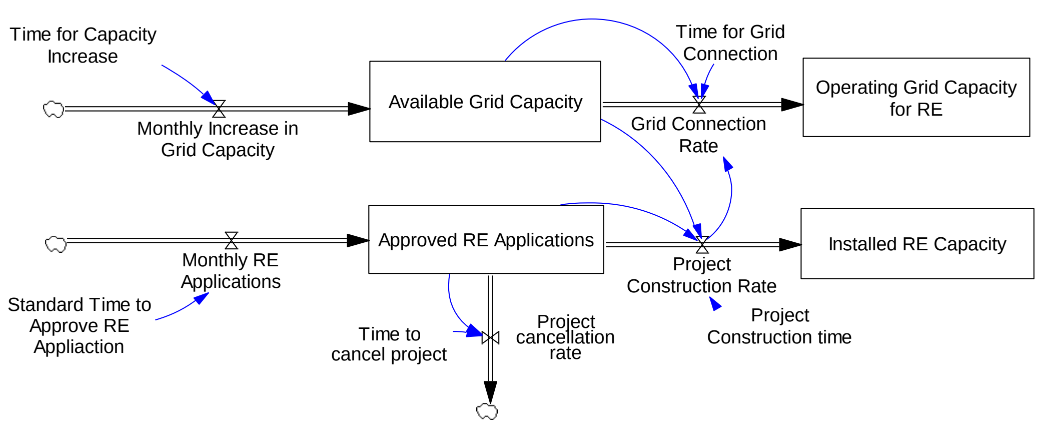

Figure 6-5: Renewable energy (RE) and Grid Capacity stock-flow system-dynamics structure

Source: Author's drawing

The basic idea of the model is that its structure should restrict the project construction rate from going beyond available grid capacity as shown in Figure 6-5. The model tests an alternative solution to increasing the grid capacity, by reducing the supply of conventional energy and reassigning the grid capacity previously used for it, to renewable energy. Although the model mainly focuses on the quantities of nuclear energy, the model can be generalized to include fossil fuels. The reason behind this selection is due to the public debate about achieving zero nuclear energy, as well as the fact that the Japanese energy mix has been sustained for the last three years with nuclear energy generation suspended. Based on that, the model was intended to determine whether renewable energy could be promoted in place of nuclear energy.

6.4.2 Model Assumptions

The model deals with the peak supply of renewable energy and considers an aggregate view of the grid capacity of Japan as one quantity. In addition, short-term challenges related to real-time operational matters, the variable supply of electricity, frequency differences, and other technical issues have been ignored as they are outside the scope of this model. Because the target is moving over time, it would take some time for the concerned authorities to release changes in targets. To accommodate this situation, smoothing with a time horizon of three months was used to model the perceived lag between the perceived and the actual targets. According to the targets roadmaps announced by the Japan Photovoltaic Energy Association (JPEA) and Japan Wind Power Association (JWPA), solar energy would have the largest share until the year 2020, and wind energy would constitute 10% of the overall share. Therefore, the approved applications (or reservations) for solar energy, shown in Figure 6-1, are used to represent the moving target for renewable energy. The target capacity was set to 70 GW. The predefined available grid capacity ready for connection was set to 5.6 GW. In addition, the model assumed that each unit of renewable energy would correspond to one unit of the electric grid.

6.4.3 Model Results and Analysis

The model has three scenarios: 1) grid expansion, 2) grid expansion with reduced conventional energy, and 3) renewable-energy target estimation.

6.4.3.1 Grid Expansion Scenario

The base simulation runs (named “current”) assumes a development time for grid expansion of 10 years. Figure 6-6 below shows how the available grid (5.6 GW) is first utilized until Month 18 when the grid bottleneck is realized. At this time, RE applications start to pile up, and the pace for expanding the grid accelerates towards the target. This scenario is very similar to the real situation in Japan.

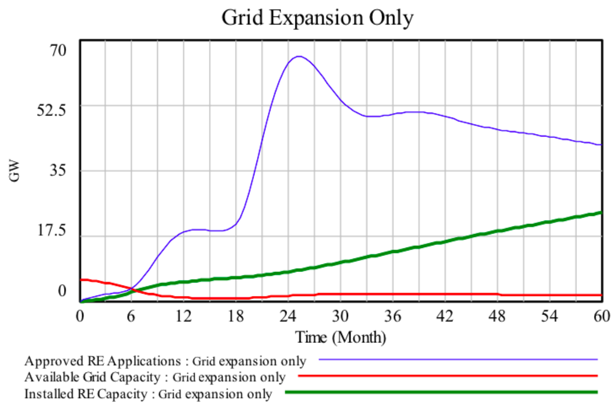

Figure 6-6: Renewable energy growth under grid-capacity-expansion scenario

Note: The grid capacity growth is extremely insufficient to incorporate the accumulated applications for the renewable energy projects. Source: Author simulation

When considering the monthly rates, Figure 6-6 shows two important points. The first is the behaviour affecting cancelled and abandoned applications. Although the applications in this model are measured in GW of electric power, and does not quantify the number of projects, the project size in watts still provides an implicit hint about the number of projects. The size of renewable energy projects usually varies between a few kilowatts (kW) to about 500 MW. If 2 MW is assumed to be an average project, each 1 GW (1000 MW) installed would mean roughly 500 projects, to provide perspective. Therefore, the pattern of cancelled and abandoned projects was a clear red flag about the upcoming problem of grid expansion. The second point is that, as the delay to approve RE applications increases, market observers receive false signals that that the industry is booming. The fact that renewable energy development is mainly driven by the profitability levels from fixed feed in tariff prices, results in severe competition among renewable energy developers as the tariff prices begin to decline more rapidly. Once the grid limitation becomes a widely known problem, the renewable energy supply begins to stabilize.

6.4.3.2 Grid expansion with reduced conventional energy scenario

The second scenario involves the release of grid capacity reserved for conventional energy, and reusing it for connection of RE projects. Consider the nuclear energy situation as an example. The cumulative nuclear energy generation in Japan was around 40 GW. The nuclear reactor shutdown process is assumed to last at least two more months because operation of most of the nuclear reactors is still suspended (WNN, 2015). The scenario clearly shows that renewable energy development could acquire a faster trend, although it will still require more time to reach the 70 GW target.

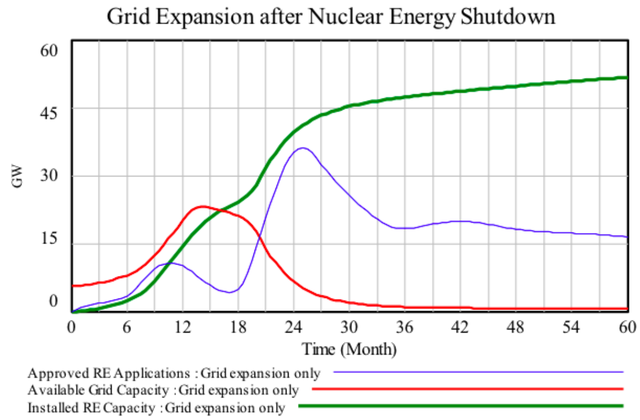

Figure 6-7: Reduced conventional energy scenario

Note: The effect of limited grid capacity on the application approval rate and installed capacities. The decline of the application indicated in the figure might represent a collapse in the renewable energy market (solar PV in this case) and the migration of investors to markets outside Japan similar to the case studies discussed in European countries. Source: Author's simulation.

Considering the monthly rates of development, the scenario suggests massive installations of renewable energy within a short period, with an average installation rate of 2 GW/month for the first two years. This rate slows dramatically in the third year. This scenario shows how it is possible to recover from energy shortages resulting from the nuclear reactor shut down for inspection and maintenance after the 2011 Fukushima incident. It also points out that, had such a scenario been planned for, a tremendous share of recent energy costs could have been saved from being spent for LNG gas at skyrocketing prices.

6.4.4 Renewable Energy Target Estimation

Figure 6-8 shows a comparison between the scenarios discussed above while focusing on when the renewable energy target could be achieved. In addition, because the grid capacity expansion might have different timeframes depending on many factors, different grid capacity expansion times were considered. The results show that although using renewable energy in place of conventional energy might not achieve the target precise as expected, it is the fastest approach to integration of renewable energy. The pace of growth slows down after 24 months because all the available grid capacity reserved for conventional energy would have been replaced with renewables. The 10-year scenario was used to show what impact this substitution would have in achieving the long-term targets.

(a)

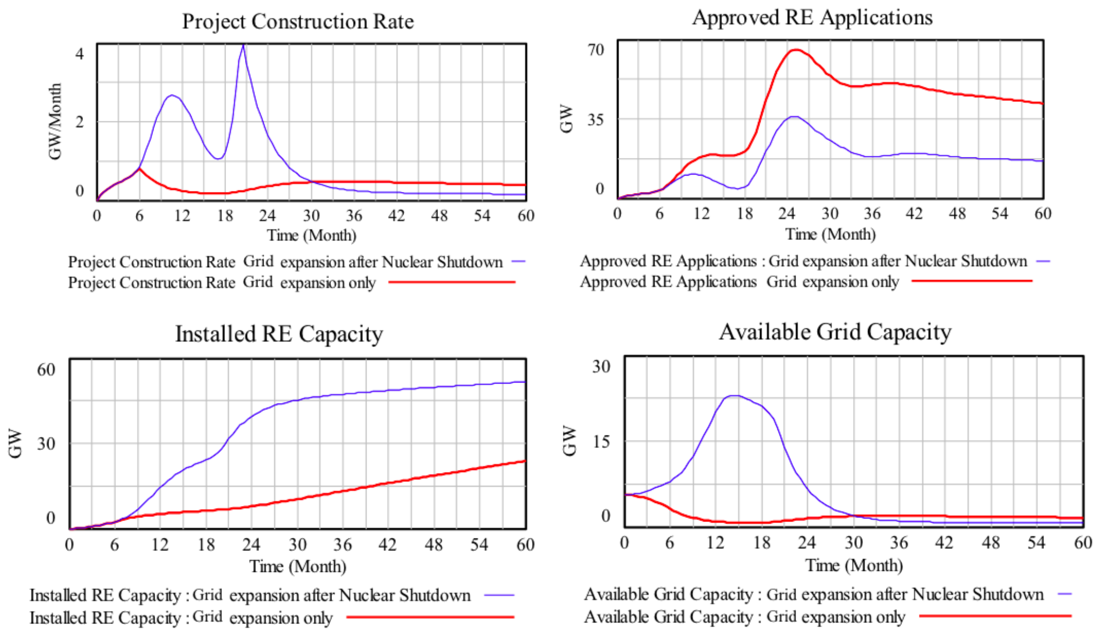

Figure 6-8: Renewable-energy growth-scenario comparisons

Source: Author simulations

6.5 Policy Implications and limitations

The conventional energy shut down scenario provided a faster growth rate for renewable energy. However, in reality, the growth rate is also determined by many other factors, including the cost curve of renewable energy technologies, the feed in tariff price and business profitability, the availability of talent and resources, as well as the regulated capacity cap that sets the maximum capacity to be installed annually. The feed in tariff degression rate, or the rate at which the feed in tariff price is reduced, is an important design policy element that can regulate the distribution of growth over time. A wider growth-distribution pattern over time is expected to provide longevity and to be more suitable for the renewable energy industry. The second scenario also shows that once the conventional energy is replaced, the remaining capacity required for transmission is built. This allows projection of the grid capacity expected to be installed. By comparing the grid capacities to be installed in the first and second scenarios, it can be demonstrated that the grid development cost can be reduced significantly. In addition, because the renewable-energy technology cost reduction is a primary goal of feed in tariff policies, the modelling simulations results show that the pace of renewable energy development could be increased. This is shown in the second scenario and implies that mass production could be achieved and would rapidly reduce the cost of the required technology. The lower the cost for renewable energy technologies, the lower the electricity generation cost from renewable energy power plants, meaning low electricity prices for consumers. This in turns creates a positive feedback effect that could help in achieving the target in an even shorter period.

Substituting all conventional energy with renewable energy is still a debatable subject. For example, some researchers claim that the introduction of variable supplies of electricity from renewable power plants requires a stabilizing supply of non-renewable energy such as LNG gas (Q. Zhang, Ishihara, Mclellan, & Tezuka, 2012; Y. Zhang, Song, & Hamori, 2011) On the other hand, some recent reports state that a 100% renewable energy mix is possible in the medium or long term (REN21, 2012; WWF Japan, 2011). In either case, given the benefits discussed in this paper from the faster growth of renewables, the replacement of fossil fuels could be expedited whenever possible.

Given the geographical distribution of natural resources and existing grid interconnection bottlenecks, the aggregate view of the grid in the model provides accurate information about where the grid expansion should take place. A more detailed model would be needed to identify the regional interconnection limits. In addition, while the model uses long-term targets to identify the level of renewable energy supply, the model structure could be enhanced to include the feed in tariff calculation process to show how the tariff level could be adjusted to manage development. The feed in tariff price and annual capacity cap are imperative measures that could improve the model's accuracy.

6.6 Summary and Conclusions

The rapid development of renewable energies caused by the feed in tariff has had critical effects on the infrastructure and required different planning and investments mechanisms to allow for distributed generation and variable supplies of electricity. In this chapter, the grid capacity limitation in Japan was discussed, as was its impact on the future growth of renewable energy. A system dynamics simulation was used to model and simulate two main scenarios to analyse possible growth patterns and behaviours. The first scenario considers the growth of renewables given expanded capacity of the grid. The second scenario assumes shut down of conventional energy and reassignment of the energy capacity reserved for it, to support the expansion of renewables. The model succeeded in replicating past behaviour and in identifying some key market indicators. The results show that replacing conventional energy power plants is a good strategy that would enhance renewable energy development in Japan in a shorter period of time, reduce policy budget costs, and more importantly, resolve the current bottleneck resulting from limitations of the electric grid. It found that substantive costs could be prevented if the second scenario were implemented to speed the growth of renewable energy, instead of increasing imports of LNG gas or crude oil.

The conclusion of the 4th basic energy plan in securing the role of nuclear energy in the future energy mix has been criticized for lacking clarity in the strategy formulated and for causing ambiguity for the future of renewable energy development. Suwa and Jupesta explained that technology diffusion policies fail, because they "demand extensive inquiry as to its definition, motivation, and drivers for implementation", in addition to "the lack of understanding about nature, scope and obstacles related to them" (Suwa & Jupesta, 2012). The reluctance to take actions to resolve the grid connection issue among the five utilities for over a year has spread fear among investors, who now question the seriousness of the Japanese strategy for achieving renewable energy targets. Any perceived inability to mass-produce these technologies is primarily linked to the failure of policy in effectively facilitate the obligation to ensure convenience of renewable energy deployments and required actions aggressively. As Suwa and Jupesta explained, that the failure in diffusing renewable energy sources in Japan, for example, is attributed to the adoption of a sub-optimal policy in which policy makers favour political judgment and biases, rather than economic rationale and empirical evidence (Suwa & Jupesta, 2012). Although the recent development since the introduction of the feed in tariff policy in 2012 until 2015 have seen an active growth, the future remains highly uncertain.

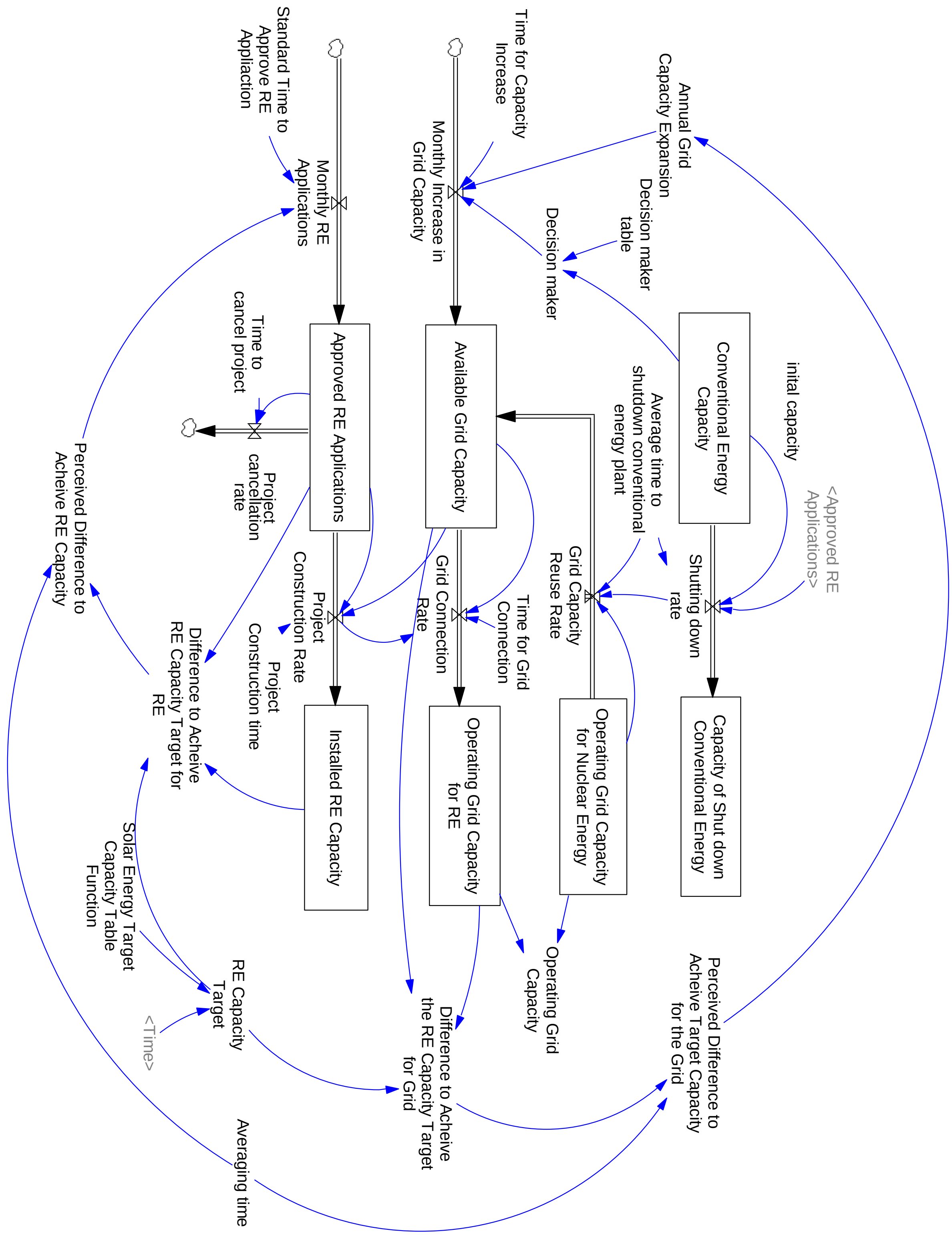

Figure 6-9: The system dynamics model

7 Feed in Tariff Policy Effect on Wind and Solar Energy Innovation in Japan

Overview

In this chapter, the impact of the Japanese feed in tariff policy on solar and wind technologies was re-investigated. Comparative analysis was used to verify this argument. Data from existing literature, as well as patent offices in Europe and China, were compared. This chapter provides two conclusions. First, unlike other country cases where FIT impact has significantly varied, this study found that the feed in tariff has had a positive effect on innovation in Japan. This is an important contribution to the common wisdom consider R&D spending have the highest impact on innovation activity. FIT was found to generate high demand for the technology deployment, which increases competition in the market and consequently results in continuous technology enhancements. This in turn also has resulted in outsourcing these industries to China to maintain cost efficiency. The analysis shows that patents for renewable energy technologies declined in Europe and Japan, but significantly increased at the Chinese patent office. One possible explanation is that companies find it more effective to patent their intellectual property where the manufacturing is based. The second conclusion is that patent count research alone is inadequate to deduce fair conclusions. Instead, it is necessary to conduct innovation-impact assessment research by descriptive or comparative analysis of activity at the major international patent offices in order to obtain an accurate conclusion.

7.1 Introduction

Research and development are essential for technological discovery, progress, and cost reduction. One of the renewable-energy promotion policy objectives is to spur innovation to achieve technological progress in the field of renewables. As shown in previous chapters, the feed in tariff has caused significant demand for renewable energy technology. The efficiency requirements set by regulators ensure a trend of technological development. Nevertheless, the effect of the feed in tariff policy on innovation is still hotly debated.

7.2 Literature Review

Patent activity in the renewable energy sector began increasing in the 1990s. In 2009, the World Intellectual Patent Organization (WIPO) conducted a landscape survey of 77,813 renewable-energy patents filed at major patent offices around the world. In that survey, 55% of the patents had been filed in Japan, followed by the United States and Europe. The WIPO analysis found that patent volume increased by 10% during the 1990s, and by 25 percent between 2001 and 2005 (WIPO, 2009). In another study conducted by the United National Environment Program, the European Patent Office (EPO) and the International Centre for Trade and Sustainable Development (ICTSD) showed that between 1978 and 2006, the number of patents increased by a factor of 2–6 (for solar technology ~ 6× and ~ 5× for wind technologies) (UNEP, EPO, & ICTSD, 2010). These indicators show a growing interest in these two industries, in particular. Studies show that there is a positive correlation between the increase in a number of patents for wind technology and wind deployments. However, this conclusion cannot be generalized to other technologies. For fuel cell technology, for example, the increase in patent volume did not result in significant deployment as occurred in the case of wind energy. This could be considered evidence for the positive role of promotion policy in the technology diffusion process (IRENA, 2013).

One popular argument suggests that spending on the feed in tariff might not necessarily spur innovation exclusively limited to renewable energy technologies, but through technology spill over, might also benefit other technologies (Mitchell et al., 2011). On the other hand, (Böhringer, Cuntz, Harhoff, & Otoo, 2014) conducted a study of the effect of the feed in tariff in spurring innovation, using 20 years of data from Germany. They concluded that despite the high feed in tariff spending, indications that the policy increased innovation in renewable energy technologies like solar photovoltaic, wind, and geothermal energies, were insignificant. In fact, their analysis showed that the feed in tariff had affected innovation for biomass and hydropower generation technologies, and asked policy makers to be cautious in promoting this policy. (Johnstone, Haščič, & Popp, 2010) used panel data from patents of 25 countries to assess the impact of promotion policies on the innovation of renewable energy technologies. The study indicated that R&D spending is a major determinant of innovation for renewable energy technologies. In addition, it found that the effectiveness and efficiency of renewable energy promotion policy depend on the energy source. For example, price-based instruments like feed in tariff and tax incentives were found to have positive innovation impacts on solar photovoltaic, biomass, and waste-to-energy technologies. Whereas quantity-based instruments were found to be the most effective in promoting innovation in wind technologies. In addition, the study found that the effect of promotion policies on innovation depends on the technology cost. For instance, quantity-based instruments induce more innovation for competitive technologies like wind energy, while feed in tariffs are more appropriate for costlier technologies like solar photovoltaic. One explanation for such surprising results is that the feed in tariff incentives encourage incremental innovation rather radical or disruptive innovation. It was argued that the design feed in tariff policy in Germany itself does not promote innovation but rather, aims for technology efficiency enhancements via learning by doing and economies of scale. It has to be noted that incremental innovation via learning by doing are not registered as patents, as is the case with radical innovation. The enhanced efficiency focused design of the feed in tariff is critical and has an impact on the type of technologies to be manufactured and used. From an investor's point of view, this design of feed in tariff allows the use of existing technologies as long as they are cost effective rather than striving for new technologies. From the manufacturing point of view, development of new technologies is very costly and mainly influenced by market demand. Low demand for innovation and technological change eventually slows down the rate of radical innovation.

One indicator of technological innovation is the count of patents filed for a certain technology. The technology patent count is used as an indicator for technological change, firm strategic position, and assessing scientific progress (Danguy, De Rassenfosse, & Van Pottelsberghe de la Potterie, 2010). There is concern that using patents as indicators might not be suitable because patents quality and value differ across industries and sectors (Böhringer et al., 2014). A report by the International Renewable Energy Agency (IRENA) indicated that patent information could provide valuable insights. For example, it could be determined which countries have high innovation activities, or which countries have potential markets where intellectual property rights need to be protected. Patents also provide insight into development trends for certain technologies, or into the trend of technological knowledge transfer, as well as into research cooperation between countries (IRENA, 2013). In addition, there are very few cases in which significant inventions have not been patented (Dernis & Khan, 2004; Van Pottelsberghe, Denis, & Guellec, 2001). Therefore, a patent count is considered useful as a legitimate indicator of innovation (Johnstone et al., 2010; Leydesdorff, Alkemade, Heimeriks, & Hoekstra, 2014; Wakasugi & Koyata, 1997). Although patent count is commonly used method for assessing technological innovation, there are several methods by which to count patents, and each may lead to different interpretations (OECD, 2009; Van Pottelsberghe et al., 2001). Special care has to be taken to reduce bias when selecting patent indicators of innovation.

Inflation of patent counts is an old problem that leads to undermining trust in patent statistics and their conclusions about innovation activity. (Guerrini, 2014) traced the use of a simple patent count as an indicator of innovation, to the year 1869. In that year, the Annual Report of the Commissioner of Patents (USA) revealed concern of quality over quantity of patents, resulting in what was called the "quality crisis" (Guerrini, 2014; USPO, 1869). The massive increase in patent filing in the China

Patent Office SIPO is highly argued among researchers. Figure 7-1 shows cross-country filing data for different patent offices. As in other countries, it was noticed that Chinese research institutions and companies are mostly filing at their local patent office. However, in comparison with other such offices, the patent filing activity in China is staggering. The statistics listed at the SIPO website showed that Chinese innovators filed around 800,000 patents in China, in the year 2014 alone (SIPO, 2015).

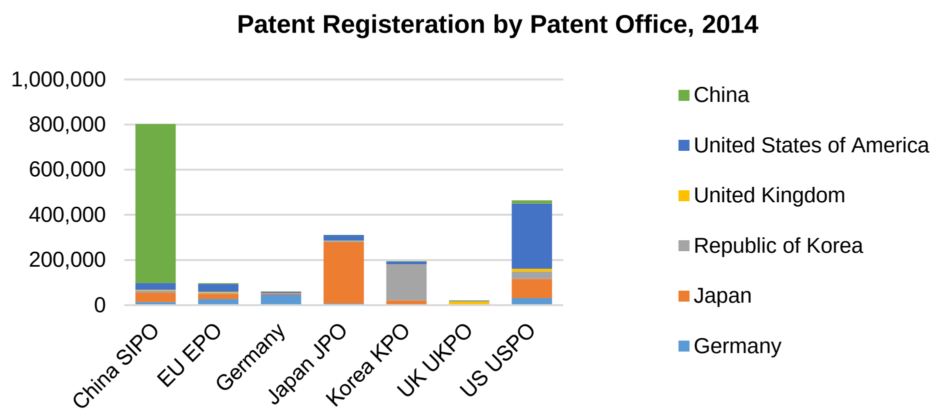

Figure 7-1: Patent registration by patent office application filing

Source: (WIPO, 2014) Adapted by the author

However, there are many patent-count indicators devised to increase the accuracy of innovation activity-measuring research. For example, the corrected count of national priority filings (NPFCORR) developed by de Rassenfosse captures the patent by inventor's country, regardless of where the patent was filed (de Rassenfosse, Dernis, Guellec, Picci, & de la Potterie, 2011). This indicator is broad, and it incorporates both high and low-value patents. Moreover, this indicator generally favours patents from Japan and South Korea because their proportion of R&D is lower than their proportion of patents filed. In addition to the NPFCORR, the statistics of major patent offices (e.g. European Patent Office: EPO, the United States Patent Office: USPO, Japan Patent Office: JPO) may be used directly as indicators. However, each of these regional indicators can have a bias in reporting due to two factors: home country bias, meaning that companies usually file patents at the patent offices where they are located, or competitive market bias, meaning that demand increases in certain markets, making them more favourable for filing patents. The EPO in particular, requires high patent filing fees as a measure to filter low-quality patents, yet this action is regarded as ineffective (Danguy et al., 2010). However, a more recent study found a positive correlation between the cost of filing (fees) and patent quality (De Rassenfosse & Jaffe, 2014). The OECD has another indicator called the TRIADIC indicator, which was developed more than a decade ago. For this indicator, a patent has to be filed at the USPO, JPO, or EPO to be recognized as a quality patent in the OECD patent database (OECD, 2009). Comparative studies have found that the TRIADIC indicator is more reliable for innovation analysis studies (de Rassenfosse et al., 2011).

Besides the patent count, there are several other measures used to assess innovation activity (see Table 7-1). Actually, some researchers argue whether patents themselves have a significant role in innovation (Haščič & Migotto, 2015). It can be concluded that a mixed innovation measure approach is necessary to clarify the ambiguities and doubts about the results from the patent count research method.

Table 7-1: Innovation measures

Stage of Innovation Cycle	Measures	Pros and cons
Technology development	R&D expenditure and personnel	+ ease of communication
		- input measure of innovation
		- difficult to identify
		- data availability: only OECD countries and some sectors
	Scientific publications	+ geographical and temporal coverage
		+/-possible to identify some environmental aspects
	Patented inventions	+ measure innovation by definition
		+ measures (intermediate) outputs of innovation
		+ granularity, possible to identify specific environmental aspects
		- does not cover incremental innovation
		- varies across patent offices
		- ambiguity and absence of common technological classification and descriptive method
Technology diffusion	Patenting activity	+ global coverage, long time series
		- capture only technological innovation
		- timeliness
	International trade	- difficult to identify environmental commodities
		- most traded goods are not innovative products
Technology adoption	Licensing surveys	+ measure of innovation value (royalties)
		- cost and confidentiality
	Innovation surveys	+ can measure organizational and marginal innovations
		- availability, cost, and comparability

Source: (Haščič & Migotto, 2015)

7.3 Impact of Feed in Tariff Policy on Innovation

The feed in tariff focus on cost reduction to achieve a higher return on investment led to outsourcing the manufacturing process to countries with low labour cost, particularly to China. The accumulation of outsourced supply increased the comparative advantage of the manufacturing industry in China and increased the level of cooperative research and knowledge transfer, especially in the field of solar photovoltaic and wind technologies. The emergence of renewable energy policies in China and the beginning of incentives created competition between outsourcing and national companies. Consequently, patenting and intellectual rights protection processes have gradually shifted from major international patenting offices like the USPO and JPO, to the Chinese patent office (SIPO). The filings at SIPO have increased the national knowledge stock of patents and helped Chinese industry to shift from imitation to indigenous innovation. Another recent study (Groba & Cao, 2014) revealed that filing in SIPO and importing technology from China did not lead to bilateral knowledge transfer. This is because the manufactured products are exported globally, not only used in the country where the patent originated. Data from Japan, the EU, and the United States about imports of solar and wind technology products, show that in general, the countries where feed in tariffs were implemented have high imports from China. On the other hand, imports were found to be less in the case of countries that implemented tax incentives, or quota obligations, instead of a feed in tariff policy (Groba & Cao, 2014).

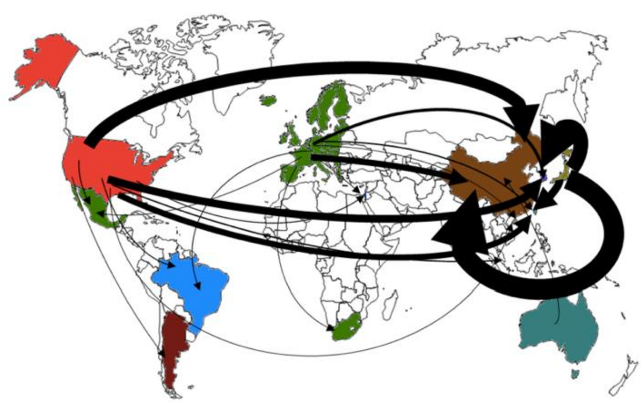

Figure 7-2: International technology transfer of PV energy technologies 1988-2007

Note: The thickness of the arrows represents the intensity of knowledge transfer and research cooperation activities in the field of solar PV energy development in the indicated period. Source: (Haščič, Johnstone, Watson, & Kaminker, 2010)

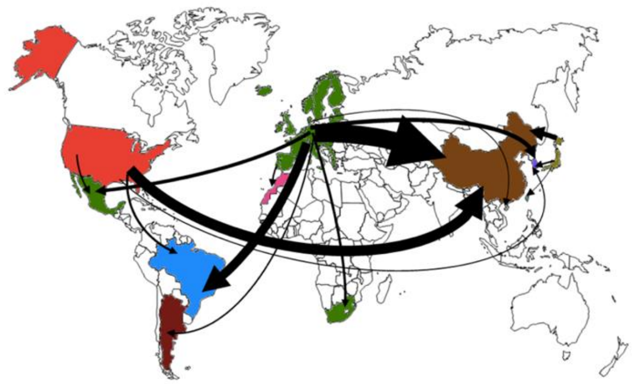

Figure 7-3: International technology transfer of wind energy technologies 1988-2007

Note: The thickness of the arrows represents the intensity of knowledge transfer and research cooperation activities in the field of wind energy development in the indicated period. Source: (Haščič et al., 2010)

(Bettencourt, Trancik, & Kaur, 2013) studied patterns of global patent filing to explain the recent boom in innovation in wind and solar technologies. They showed that public R&D cannot explain the pattern funding alone; it has to be complemented with fast growth in the deployment of those technologies. In this study, it was found that a shift in policy focus towards innovation is needed to achieve further cost reductions timely and cost-effectively. We also found that the industry-wide oversupply and unsustainably low prices of PV modules present a barrier for incentivizing and commercializing innovation through "demand-pull" policies (Zheng & Kammen, 2014). In fact, this argument is common among innovative industries, like the pharmaceutical industry. A recent study argues that patents for incremental innovation are as important as for disruptive innovation, considering their novelty and significance as well as the fact that they follow the same standards (Lybecker, 2013).

7.4 Objective and Methodology

This objective of the study is to verify the impact of the feed in tariff on the innovation activity in the renewable energy sectors using the patent count data. These data were obtained from the most active companies filing patents for photovoltaic applications. The World Intellectual Patent Organization (WIPO) list of selected companies was used. The term "Photovoltaic" from the English language version of the Japan Patent Office (JPO) website was used as the keyword to search and collect the relevant patents in the period between 1980 and November 2015.

7.5 Results

The results show an increase in patent activity during three periods between 1980 and 2015. A dramatic increase could be observed in the patent activity in particular after the resumption of support for renewable energy via the FIT policy in 2009. The initial survey of the results shows that although WIPO results suggest that Toyota has the largest share of PV patents, the analysis of patents at the JPO office did not provide similar results. The analysis determined however that Mitsubishi Corporation was at the top of the list, followed by Sharp, Hitachi, Toshiba, and Kyocera. In addition, major Chinese companies with a significant share of the Japanese market (e.g. Suntech, Trina Solar, Yingli Solar or Canadian Solar) filed no patents. Korean manufacturers on the other hand (e.g. LG, and Samsung) did have some filings, but these were very limited. This could be regarded as evidence that the JPO was not a primary filing office for foreign manufacturers. Moreover, for the year 2015, although the patent statistics were retrieved in late November, the results showed comparatively very low filing activity, compared with the previous four years.

A closer look at the patenting activity for the top five Japanese manufacturers shows no significant increase for Panasonic and Sumitomo, but a noticeable increase for the other three manufacturers: Mitsubishi, Sharp, and Toshiba. In fact, it shows a reverse effect for companies like Kyocera and Toyota for which patents started to increase in the year 2012. Other companies exhibited a declining trend from the year 2012 onward, like Sony. Foreign manufacturers like LG and Samsung started filing patents for the year 2012, which infers the beginning of the solar boom in Japan. Considering the average among all 12 of the major manufacturers filing at the Japanese patent office, it is clear that the patent filing activity increased, on average, among all companies after the year 2012.

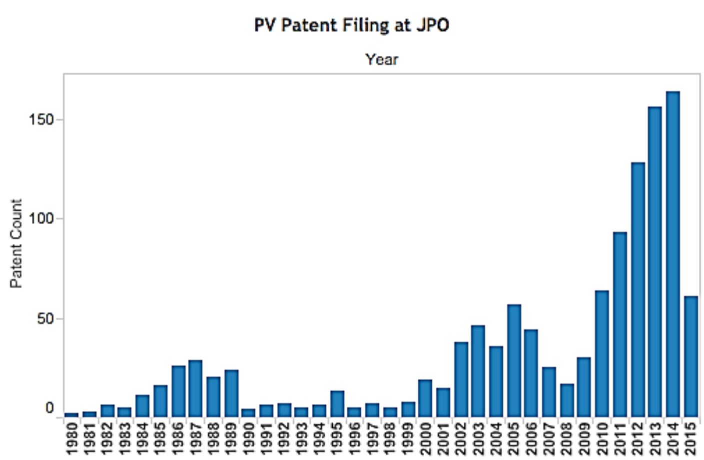

Figure 7-4: Patent filing activity in Japan for PV applications

Source: Author’s drawing with data obtained from Japan Platform for Patent Information (J-PatPlat, 2015)

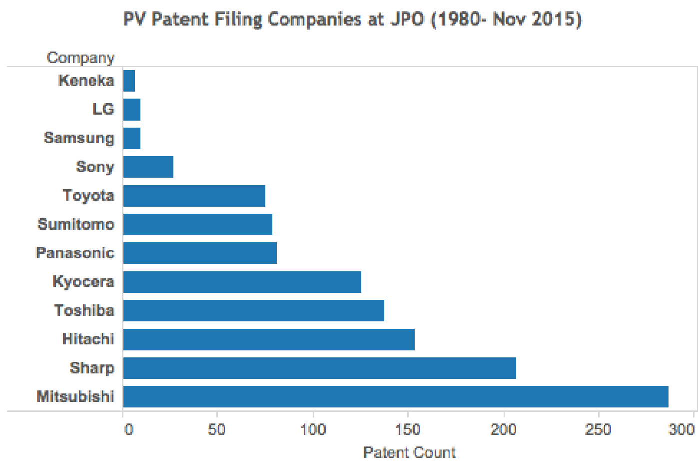

Figure 7-5: Companies with the largest number of patent filings at JPO

Source: Author's drawing with data obtained from Japan Platform for Patent Information (J-PatPlat, 2015)

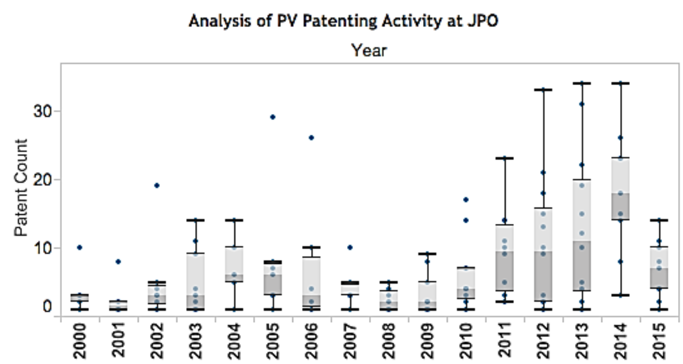

Figure 7-6: Analysis of the annual average for patent filing among the selected companies

Source: Author's drawing with data obtained from Japan Platform for Patent Information (J-PatPlat, 2015)

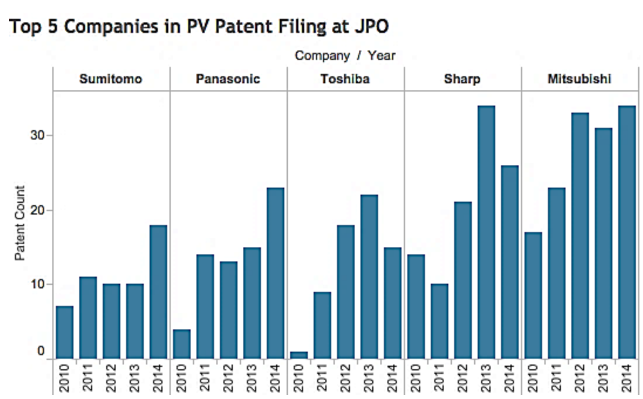

Figure 7-7: Five-year analysis of the most active companies filing PV patents at JPO

Source: Author's drawing with data obtained from Japan Platform for Patent Information (J-PatPlat, 2015)

7.6 Conclusions

R&D funds and renewable energy promotion policies have a crucial effect on the innovation activity of renewable energy technologies. Although the credibility of measuring innovation activity using patent count is argued among researchers, the patent count remains the most common approach used in the literature. In this study, patent count provided an indication about how the market reacted to government policies and to strategies for energy transition. This chapter aimed to investigate the benefits of feed in tariff incentives in spurring innovation activity and technological progress. The study questioned the innovation activity for the technologies that generally benefited the most from the high tariffs, namely wind and solar technologies. The impact of the feed in tariff policy was investigated in Japan, since the research literature, which investigates the feed in tariff policy, is comparatively low when compared with other countries, or when compared with studies that investigate R&D funds on innovation and technological progress.

The results of this research show that feed in tariff policy has been much more effective than other policies implemented in Japan. However, patent activity analysis did not show evidence that innovation leads to direct effects on substantive cost reductions. Despite the research in Japan for renewable energy technologies, and for photovoltaic technology, in particular, the cost of photovoltaic modules in Japan remains the highest globally. As shown in the research literature, knowledge transfer and research cooperation play a major role in the commercialization process of patented technologies. Some argue that the high Japanese PV cost can be justified since the market standards in Japan requires strict quality assurance, despite the fact that raw materials, manufacturing processes, and international certifications are generally the same across the industry. Yet it is unclear why the cost of Japanese PV products is higher than German modules, which share equivalent quality standards and measures.

The results of this study indicate that the feed in tariff has had a positive effect on innovation. The high demand for deployment of solar and wind RE resulted in outsourcing these industries to China. The analysis shows that patents for renewable energy technologies declined in Europe and Japan, but significantly increased in China. One possible explanation for this is that companies may find it more effective to protect their intellectual rights where the manufacturing is based. This is actually supported by a study (Danguy et al., 2010) that revealed an increase in patent filing in countries with stringent IP-rights protection. Moreover, it was determined that patent count research alone is not sufficient to deduce fair conclusions. Instead, innovation-impact-assessment research using descriptive or comparative analysis among the major patent offices is needed to obtain accurate conclusions.

7.7 Research Limitations

This study has several limitations pertaining to patent data. These limitations are related to the differentiation of the technologies referred to in the patent statistics. For example, the OECD statistics list an aggregated index for environmentally related technologies of power generation and network transmission technologies under one category. The EPO database, on the other hand, provides a detailed breakdown of the technologies related to solar and wind. However, patents of manufacturing equipment for wind and solar technologies are not listed. In addition, the data in patent databases lag considerably and, therefore, do not reflect recent changes in the renewable energy policy or industries (EPO, 2015; Groba & Cao, 2014; IRENA, 2013; OECD, 2015; WIPO, 2014). In addition, there is a delay period of 18 months between the filing and public disclosure of patents, known as the "publication lag" (Haščič & Migotto, 2015), and this delay makes it quite difficult, at this time, to assess the impact of the feed in tariff policy so recently enacted (mid 2012).

8 Analysis of Feed in Tariff Policy Impacts on Energy Transition and Climate Change Mitigation in Japan

Overview

In this chapter, the effect of the feed in tariff policy on the energy transition in Japan is discussed and compared with cases in the European Union and the United States.

8.1 Introduction

Energy transition or shifting to a low-carbon energy mix that enhances energy security and stability is a strategy developed in Germany through what is called *Energiewende*. The low carbon energy mix is designed with a high proportion of renewable energies as well as utilization of fossil fuel sources with advanced technologies that limit their emissions. The feed in tariff policy, because it scales up renewable energy development, plays an important role as a mechanism for achieving the energy transition. The energy transition, however, entails many questions related to the limits of the renewable energy share given the challenges related to renewable energy supply variability and predictability, energy storage, grid capacity, and electric market regulatory reform status.

8.2 Literature Review

There are a considerable number of studies that have discussed the alternative energy transition in Japan (Berraho, 2012; Hong, Bradshaw, & Brook, 2013; Komiyama & Fujii, 2014; Pollitt, Park, Lee, & Ueta, 2014), and those that have considered energy mix scenarios in Japan with up to 100% RE (Esteban & Portugal-Pereira, 2014; WWF Japan, 2011), in Europe (Connolly, Leahy, Lund, & Mathiesen, 2009; Devogelaer et al., 2012; Hohmeyer & Bohm, 2014; Klaus, Vollmer, Werner, Lehmann, & Müschen, 2010; Pillai & Heussen, 2009; Zervos, Lins, & Muth, 2010), in Africa (Schellekens, Battaglini, Lilliestam, McDonnell, & Patt, 2010), and around the world (Connolly & Mathiesen, 2014; Jacobson et al., 2015; Jonas, 2011; Lund, Østergaard, & Stadler, 2011; Plessmann, Erdmann, Hlusiak, & Breyer, 2014; Radzi, 2009; Singer & others, 2010). A recent ambitious study by a large group of Stanford University researchers proposed solution plans for 100% renewable energy mixes for 139 countries. In other studies, the potential for energy mixes with large shares of wind and solar energies were proposed (Esteban et al., 2010; Komiyama & Fujii, 2014; Tsuchiya, 2012). Moreover, several studies were conducted about the role of energy storage in achieving a

100% renewable energy mix (Esteban, Zhang, & Utama, 2012; IEC, 2012; Komiyama & Fujii, 2014; Plessmann et al., 2014).

As mentioned earlier, some of the justifications for renewable energy promoting policies like FIT are (1) to provide a diversified energy mix that could enhance energy security, (2) to enable the energy transition plans, and (3) to help in achieving low carbon economy. The following section sheds light on some of the recent literature dealing with this aspect.

8.3 Energy Diversification and Security

A diverse energy mix is believed to increase energy security against supply disruption due to its ability to switch between alternative sources of power generation. It allows effective and defensive measures against sudden price increases or unavailability of supply. Yet the various energy sources have different levels of associated risk that impact energy security. For example, whereas coal is abundant in many countries around the world and can also be procured from global markets, oil and gas are concentrated in a few regions, and their international routes are highly vulnerable (IEA, 2006). In addition, the transportation of coal is easier than oil and gas since the latter two may require cross-border pipelines that could become embroiled in political disputes. The subject of energy security is highly debated in the literature. For example, while some (Grubb, Butler, & Twomey, 2006) consider the threats of foreign imports as increasing import dependence, other scholars find that the co-dependence between importers and exporters, in addition to the nature of global markets, are reasons not to consider such threats (Bazilian & Roques, 2008). Although high dependence on imports might be deemed to undermine energy security and supply, there are many cases where supply interruptions occurred due to local incidents. For example, interruptions in the UK were attributed to coal miners, occasional power outages, or domestic fuel blockades (Grubb et al., 2006).

Energy diversification can be studied from multiple viewpoints. (Stirling, 2010) who is a pioneer in the field of energy diversity, has explained three major dimensions of this diversity: 1) variety, which refers to the number of options available, 2) balance, or how many of the available options can be chosen, and 3) disparity, which refers to the degree the options are different from each other. Despite the significant literature developed in this field, it generally falls short of defining how much diversity is needed (Bazilian & Roques, 2008). The goal of diversity should be clarified not at the end, but as a means to achieve certain objectives at the least cost possible.

Diversification of energy technologies helps in reducing the risks of energy supply. However, diversity of the energy mix is not always considered a feature is supporting energy security. The French electricity supply system for example which is far more than 50% dependent on nuclear energy has a great focus on a single technology and less diversification. This kind of energy mix structure could be regarded as very secure because it is being protected from external political and economic change. On the other hand, it could be argued that it is highly vulnerable to generic technical faults, terrorist attacks, or nuclear accidents resulting from natural catastrophes or extreme weather events (Bazilian & Roques, 2008). The drop in coal prices has made coal imports very cost competitive amid the price increases of oil and gas. Moreover, the diminishing margins for oil and gas are largely replaced with coal, which is considered more economically stable and thus better for energy security. The old UK system was designed as a coal-oriented system based upon local coal resources and mines. However, the recent development of climate action policies and the actions of trade unions have created pressures towards diversification of the energy system and towards setting a plan for shutting down some of the largest coal-based power plants (Bazilian & Roques, 2008). Therefore, it remains relatively difficult to assess and quantify the degree of diversification needed, and this area requires further research. It has to be noted however that whether the arguments are for or against energy diversity, the final decisions must not be allowed to be determined by private or corporate self-interests (Costello, 2005).

Sigmar Gabriel, the German Energy and Economy minister who is in charge of the Energiewende, or energy transformation strategy in Germany said, "The energy transformation has the potential to be an economic success, but it can also cause a dramatic de-industrialization of our country… We need to control the expansion of renewable energy, and not have the anarchy that we have seen previously… We need to reduce costs so that it remains affordable." (Eddy, 2014). To tackle the mounting complaints from those industries, exempted companies have increased from over 53 in 2004 to 2000 in 2013 while the cost of the exemptions increased to 5.1 BEUR/year. The exemption of the tariff surcharges for energy-intensive industries in Germany, however, have been investigated by the European Union as they might have violated international trade laws (as industries were provided with subsidized energy much lower than average in European Union countries). Nevertheless, this complaint was countered by the argument that the growth of renewables in Germany was essential in reducing the technological cost. "We are trying to ease burdens that don't exist elsewhere in Europe," Gabriel said. He justified Germany's position with, "Germany is paying for the learning curve that others do not need to pay for, that we need to keep this affordable for the German industry." (Eddy, 2014).

Recently, there have been many critics of the idea of achieving an energy mix of 100% RE due to the nature of renewables (Hirth, 2013; Jenkins, 2015; MIT, 2015; Trainer, 2013). According to their views, aside from the impacts a large share of renewables might have on grid stability, and the costs incurred by subsidy surcharges or the high costs of grid upgrade and expansion, the 100% scenario is infeasible due to the marginal cost of renewables themselves. (Lew et al., 2013) explained that wind and solar integration should be curtailed.

National strategies should provide a set of policies designed to direct energy options toward meeting national goals. However, the case studies in Germany and Japan show that the development of renewables is highly influenced by the way the political leadership perceives the significance of renewable energy's role in the energy mix. It also depends on how the ruling political party trade off and balance national strategic priorities, when it comes to the energy transition. Policies are always confronted with political resistance, and so strong efforts have to be made to support the survival of green policies long enough for them to become "dominant policies". The promotion of renewable energy requires an integrated, fair, coordinated, and consistent strategy. The strategy has to be consistent in the sense that it is not changed radically with a change of ruling political parties. On the other hand, the renewable energy strategy has to be an integrated strategy in the sense that it incorporates complementary policies that promote renewable energy development among energy transition stakeholders. This means that the strategy should include and implement appropriate policies. These should not only be those needed to accelerate the deployment and diffusion of renewable energy projects, but also, those required to create the required innovation and industrial capabilities, develop human resources and technical expertise, establish a sustainable grid, and mandate effective electricity market regulations. Integrated strategies are developed and evolve over the course of the energy transition period, with periodic reviews and improvements.

8.4 Energy Transition

In a recent study (Agora, 2014), it was determined that the increase in renewable energy in Germany was indeed followed by a decline in the share of nuclear energy, as expected in the nuclear phase-out plans. On the other hand, the conventional energy, primarily LNG gas power plants could not operate profitably under the merit order scheme (or priority dispatch, which gives higher priority for solar and wind energy among all energy sources). The LNG gas was gradually replaced by cheap coal (lignite and hard coal) imported from the United States. The recent heavy production of oil and gas in the United States has been the primary reason for the dramatic increase in coal stocks and related decline in coal prices. Furthermore, the CO2 emissions laws have changed frequently in Germany since 2005 due to the launch of the European Union Emission Trading System (or ETS). The ETS system is considered a "cornerstone" of the European Union's climate change strategy, and it provides emission quotas or allowances, which can be traded between countries (EC, 2015d). The aggressive climate change measures Germany implemented resulted in an oversupply of emission allowances. These made the cheap coal stocks in the United States an attractive (and technically acceptable) option for power suppliers. The CO2 emissions declined between 2008 and 2009 due to a temporary increase in CO2 prices caused by the global financial crisis. However, since 2011, CO2 emissions have risen again due to the second oversupply of CO2 allowances (Ebinger et al., 2014). This has led to a further increase of coal-fired power plants, which contradicts the Energiewende strategic plan. For example, in the period between 2010 and 2012, 2.4 GW of lignite power plants were operational, adding about 9.4% to the electricity generated from coal. In 2012, around 8 GW of hard coal power plants were under construction (Pöyry, 2013). Although the ETS was revised in 2009 to include "backloading" which aims to decrease the allowances and increase the CO2 prices via auctions (EC, 2015c), the new reforms might not take effect until after 2018 (Ebinger et al., 2014). The ETS has failed to address long-term policies that require a substantial investment in low carbon technologies (Edenhofer, Hirth, et al., 2013). The increased number of coal power plants has had severe negative effects on the emission levels in Germany. Despite the prior efforts and significant progress in reducing the emissions by almost 24% since the year 1990, it was noted that between 2010 and 2013 the greenhouse emissions increased by 2.4%, while CO2 emissions rose by 3% (Ebinger et al., 2014), resulting in what is described as the German Paradox (Agora, 2014). According to the Energiewende energy transition plan, the share of coal-powered energy production must be reduced from 45% in 2014 to 19% by 2030 (or more precisely, reducing lignite by 62% and hard coal by 80%). On the other hand, gas production is expected to increase from 11% to 22% in the energy mix in order to Germany to achieve its climate change target for 2030 (Agora, 2014).

In Japan, nuclear energy is always justified due to the cost of its electricity. The cost of electricity from nuclear energy and renewables varies significantly, a matter that influences criticism of support for renewable energy. In a report issued by the Japanese government in 2011, the cost of nuclear-sourced electricity was highlighted to be 9 JPY/kWh, wind 10 JPY/kWh, and about 30 JPY/kWh for solar PV (WNN, 2015). However, environmentalists argued that only when the external cost of nuclear energy is internalized can a fair comparison can be reached. Nuclear external costs are primarily incurred from decommissioning, and nuclear waste management costs. Moreover, an international study found that on average 117% of nuclear-power-plant construction projects have cost overruns, whereas this percentage is as low as 1% for solar power plants, and 8% for wind farms (Sovacool, Gilbert, & Nugent, 2014). The low percentages for solar and wind cost overruns are due to technological standardization and lead project development time. In general, projects have cost overruns and time delays for reasons that can be technological (complexity), psychological (optimism bias), political, or economic (conflict of interests, strategic deception) (Anzinger & Kostka, 2015; Flyvbjerg, 2007, 2009; Flyvbjerg, Bruzelius, & Rothengatter, 2003).

8.5 CO2 Emissions Reduction

The CO2 emissions in Japan increased dramatically after the recent shutdown of nuclear reactors. Between 2010 and 2012, CO2 emissions from the ten utilities increased by 30%, which accounts for about 30–40% of total emissions. This is because imports of fossil fuels (LNG and coal) increased significantly right after the Fukushima accident. Japanese officials now plan to invest 7 billion USD to build 14 gas and coal powered plants by the end of 2014. This has not only made previous climate change goals unattainable but also resulted in a reduction of emission targets from 6% below 1990 levels (which was the most ambitious target in the Kyoto protocol at one time) to a new target that is 3% above the 1990 baseline, by 2020. The previous target was mainly estimated using an energy mix with abundant nuclear power, and assuming that future emission targets would include broadening the energy mix. Critics argue that more aggressive targets, as much as 25% or more of emission reductions, are still achievable without the need for nuclear power if the development of renewable energy sources is accelerated (Greenpeace, 2014; Tabuchi & Jolly, 2013).

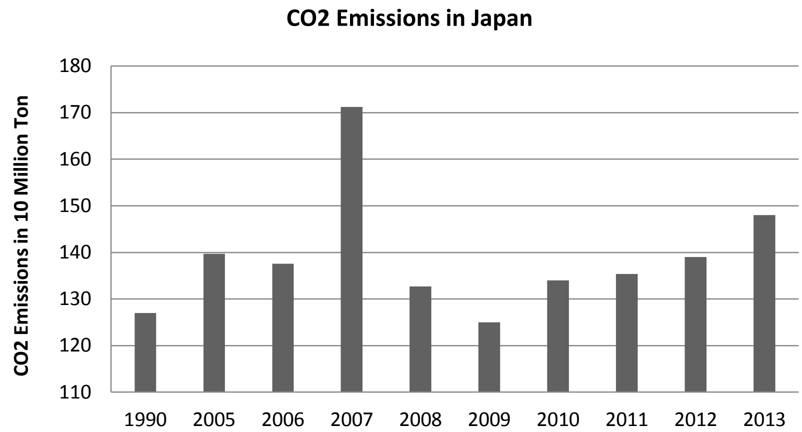

Figure 8-1: CO2 Emissions in Japan

Note: The figure was adapted by the author from (MoE, 2015).

Compared with new nuclear facilities, there is much less social resistance to coal-sourced power plants. The impacts of nuclear radiation on national and international safety are regarded as having higher priority than plans to mitigate climate change and global warming. Such comparisons have been criticized because creditable environmental and climate change studies have revealed strong links between global warming and climate change, which manifests as extreme weather events like unusually powerful typhoons and hurricanes that recently have been occurring with greater frequency. It is also true that coal-processing technologies (e.g., carbon capture and integrated gasification combined cycle or IGCC) have been greatly improved, and such improvements could help in reducing new carbon emissions. Investing in coal power plants enhances the energy security of Japan, regarding the matters of imports and continuity of power generation. When considering coal supply lines, coal is generally imported from neighbouring, politically stable countries like Australia. Moreover, using coal under these conditions means it can provide a secure, reliable source of continuous power generation with a reasonable dispatch time.

Although the spike in emissions after the nuclear accident was within the expected range and was described as “moderate”, the measures taken by the Japanese government were controversial. In order to secure the supply of coal, billions of dollars were invested in coal production outside Japan. The Japan Bank for International Cooperation (JBIC) funded 18 coal-fired power plant projects with a generation capacity of 15.6 GW. These 18 power plants were built in Indonesia, Vietnam, India, and the Philippines where the JBIC invested ~ 1–1.5 billion USD. Furthermore, Nippon Export and Investment Insurance (NEXI) also provided trade insurance for 13 coal-fired power plants with a total output of 11.7 GW and provided more than 670 million USD. In a report by the Environmental Defence Fund (EDF, a US environmental NGO) titled "Foreclosing the Future", it ranked the financial institutions that provide financing for coal-fired power plants projects over a 15-year timespan (1994–2009). According to the report, JBIC was ranked at the top of the list with about 8.1 billion USD investments while NEXI was in sixth place with about 2.1 billion USD.

The fact that Japan could survive the sudden shutdown of all but two of its nuclear reactors, which represented more than 30% of the energy mix, for two years (2011–2013), and was completely nuclear free for six months, is proof of concept that Japan has the resources, the capabilities, and the political potential for the transition to renewable energy. Moreover, the rapid development of renewable energy deployment within the first two years was a clear example of how quickly fossil fuels and nuclear could be replaced with RE alternatives while still maintaining the emission reduction targets. It has been argued that even if all nuclear power plants were replaced entirely with coal-based plants, it would still lead to a 9% reduction in emissions, which would be much better than 3.1% the above 1990 baseline. Furthermore, the nuclear versus emissions trade-off was considered a "false dichotomy" because energy-related emissions make up about 30–40% of total emissions in Japan while the remaining share of emissions of Japanese CO2 emissions is from transportation, heating, and other sectors (Greenpeace, 2014).

8.6 Conclusion

The effect of the feed in tariff policy on the Japanese energy transition was investigated. The increase of renewables was influenced by policy on the future energy mix, and ultimately by policy on climate change mitigation. It was first shown that the literature indicated that achieving a 100% RE mix based largely on wind and solar is highly arguable. This does not appear feasible, not only because of variability and predictability issues with wind and solar (i.e. the instability these might cause to the transmission network) but mainly because of the long-term economics of these two energy sources. The assessment concluded that under the merit-order effect, or priority-dispatch scheme, the relative value of wind and solar energies decreases with higher penetration. This, in turn, would reduce the return on investment of wind and solar facilities to a level where it would become difficult to recover the costs of investment. This would mean that the sustainability of such facilities would require an extension of RE subsidy programs. Given that the future cost of solar and wind electricity will be competitive with conventional energies, it becomes important to askWhether the merit order scheme should be used in the future. The literature search did not provide a viable alternative to the merit order scheme.

The primary motivation in many countries for the development of renewable energy was its use as a mechanism for climate change mitigation by reducing carbon emissions, or more generally, reduction of greenhouse gas emissions. Despite calls for accelerating the share of renewables, especially wind and solar, GHG emissions were found to be increasing in countries like Germany and Japan. The impact assessment concluded that inconsistent strategies can void the effect of a feed in tariff policy, along with all the effort and resources spent to achieve its top priorities. This is in part because, in the short and medium term, the predominance of renewable energies in the energy source mix might be impossible without the support of conventional energies. However, with the merit order scheme, which prioritizes renewables ahead of other fossil fuel technologies, fossil fuel technologies become unprofitable. This policy creates a feedback response by which the cost of fossil fuels decrease. They then become more competitive than the subsidized renewable energies. Cases from both Japan and Germany demonstrated such market dynamics, despite massive resources spent to reduce carbon emissions. Climate mitigation policies have to be aligned consistently to support the feed in tariff policy if they are to be effective. Moreover, very limited support and subsidies should be provided to fossil-fuel based power generators during the transition phase, until the share of renewable energy, as well as the infrastructural technologies, become more reliable and resilient. Furthermore, the fossil-fuel-based power generation market and fossil fuel investments should be monitored and controlled to limit the excessive increase in GHG emissions. Finally, the study investigated the role the nuclear option in the future energy mix and found that renewable energy options are far more cost effective and feasible than nuclear options when external costs (e.g. recovery from accidents, decommissioning, radioactive waste management for 10,000 years or so) of nuclear energy are included. This is not to mention the environmental hazard it poses and safety issues with international consequences. The study concluded that because Japan energy resources could sustain with no nuclear energy reactors running, zero nuclear option or limited use of nuclear energy should be seriously considered. Although one justification for nuclear energy is its reduction of carbon emissions, it has been argued that the largest share of carbon emissions is not caused by energy generation but rather by transportation, heating, and other sectors. Therefore, the emissions from fossil fuels are still less than the projected trends. Moreover, although nuclear energy is regarded as a zero-carbon energy source, it is found to be emitting hazardous GHG emissions. Consequently, in order to utilize the feed in tariff policy efficiently, the use of nuclear energy has to be strictly limited.

Conclusion

The aim of this study was to explore and assess the effects of the feed in tariff policy implemented in Japan. The development of solar and wind energy – even though partially in the case of wind – has benefited the most from policy support, compared with other renewable energy technologies. A large number of studies have conducted assessments and evaluations of the efficiency and cost effectiveness of the feed in tariff. However, a relatively small number of studies have been conducted to explore multiple-objective assessments of the effects of this policy. This assessment was conducted using system dynamics methodology to trace logical causes and relationships. The objectives assessed were profitability, supply, planning, innovation, energy transition, and climate change mitigation.

Study of the profitability of feed in tariff prices in Japan revealed that the self-consumption policy used for the residential sector might impact their payback period. This is especially true considering the different amounts of power consumed by different households around Japan. The solar irradiation resources are not equal due to Japanese geography, so considerable variation in the output of solar electricity should be expected. Consequently, there is also considerable variation in the revenues generated and thus very different payback periods. It is recommended to have a feed in tariff zoning system, where the feed in tariff prices are based on the average solar irradiation of each administrative unit. The model results also indicate that future tariff prices should maintain such level of profitability that would create a sustainable market in Japan for solar energy.

The long-term development analysis of the solar energy industry in Japan revealed some of the future limitations that could restrict its growth. Considering the legacy electricity system in Japan, the electric grid capacity is one of the greatest challenges to be overcome in the next decade. The scarcity of suitable land for large-scale solar development is another. As large facilities are installed on the remaining 'cheap' land, real estate prices will increase. This will shift development of the RE market towards the residential sector. Dealing with this will require policy reforms to provide land-price control through special taxes, or by providing permits for solar construction over agricultural land.

The short-term development analysis showed that frequent price adjustment induced a rush-to-install effect that has resulted in boom and bust cycles in the market. A causal-loop analysis and newly developed system dynamics model were used to simulate the market pattern according to historical data. This was done to analyse the effect of current feed in tariff adjustment or degression models. The system dynamics model can help to reduce the rush-to-install effects seen in Japan (and in other countries, including Germany). Unlike optimization models, the system dynamics model used here considers a realistic investor-decision-making process and is able to explain the rush-to-install effect from a developer perspective. The study found that the fluctuation pattern occurs due to time delays and to systematic non-linearities that are part of the problem studied. The simulation results showed a comparison between a continuous feed in tariff model versus a discrete feed in tariff adjustment model. The continuous feed in tariff adjustment model provides tariff-pricing patterns that are more robust and adaptive against unexpected changes in technology cost. It is also beneficial if the supply of renewable energy is guided within capacity corridors, or if an annual cap limit on supply is defined by the policy makers. This is because frequently or continuously dynamic adjustments react more rapidly to technological costs. These can be used to reduce profitability gains to reasonable IRR levels suggested by policymakers, thereby avoiding snowball effects from excessive profitability. Modelling the dynamic tariff adjustment revealed important implications for the long-term sustainability of the renewable energy industry, and use of the model allowed even distribution of feed in tariff support across the intended support period. Case studies from different European countries showed that unresponsive tariff models result in too-rapid growth in the share of renewable energy, which is favourable for environmentalists, but also results in quick, highly excessive profitability gains by investors. Such scenarios produce a skewed distribution of renewable energy deployments over time so that the cost of a certain renewable energy technology might become relatively high in comparison with other renewable technologies. Therefore, dynamic price adjustment can optimize feed in tariff policy budgets and result in less impact on electricity or energy taxpayers.

The rapid development of renewable energy sources caused by the feed in tariff has critical effects on related infrastructure and requires different planning and investment mechanisms to allow distributed generation and a variable supply of electricity. Two major scenarios under the condition of limited transmission capacity were considered, using a quantitative model of solar energy development. The first scenario included estimation of solar energy growth with plans for grid expansion. The second scenario included estimation of solar energy growth when the capacity in the electric grid usually reserved for fossil-fuel plants was reassigned for solar PV energy. The results indicated that the second scenario provides faster growth for solar and other renewable energies. It was also found that substantial savings would result if the second scenario was implemented to increase the growth of renewable energy rather than increasing imports of LNG or crude oil.

The assessment of the feed in tariff policy effect on innovation activity for renewable energy technologies revealed positive effects. Using patent count analysis involving the major companies contributing to research and development in the field of solar photovoltaic technologies, it was found that patent activity increased after the introduction of the feed in tariff policy in 2012. However, the impact of the cumulative patenting activity on cost reduction or generating cost-effective alternatives appeared questionable and should be investigated in further research. This is because the Japanese PV modules are still the most expensive in the world, compared with similar modules manufactured in Germany, let alone those manufactured in China or South Asian countries. Because most of the recent research use patent data limited to the year 2011. This means that further research should also focus on recent patent statistics obtained from different major patent offices because much of the patent filing activity has shifted to the Chinese and Korean patent offices. In addition, investigation of innovation should not be limited to the statistical significance obtained from patent count data, but should also be combined with other measures to produce more accurate conclusions.

The effect of the feed in tariff policy on the Japanese energy transition was investigated. The increase of renewables was influenced by policy on the future energy mix, and ultimately by policy on climate change mitigation. It was first shown that the literature indicated that achieving a 100% RE mix based largely on wind and solar is highly arguable. This does not appear feasible, not only because of variability and predictability issues with wind and solar (i.e. the instability these might cause to the transmission network) but mainly because of the long-term economics of these two energy sources. The assessment concluded that under the merit-order effect, or priority-dispatch scheme, the relative value of wind and solar energies decreases with higher penetration. This, in turn, would reduce the return on investment of wind and solar facilities to a level where it would become difficult to recover the costs of investment. This would mean that the sustainability of such facilities would require an extension of RE subsidy programs. Given that the future cost of solar and wind electricity will be competitive with conventional energies, it becomes important to ask whether the merit order scheme should be used in the future. The literature search did not provide a viable alternative to the merit order scheme.

The primary motivation in many countries for the development of renewable energy was its use as a mechanism for climate change mitigation by reducing carbon emissions, or more generally, reduction of greenhouse gas emissions. Despite calls for accelerating the share of renewables, especially wind and solar, GHG emissions were found to be increasing in countries like Germany and Japan. The impact assessment concluded that inconsistent strategies can void the effect of a feed in tariff policy, along with all the effort and resources spent to achieve its top priorities. This is in part because, in the short and medium term, the predominance of renewable energies in the energy source mix might be impossible without the support of conventional energies. However, with the merit order scheme, which prioritizes renewables ahead of other fossil fuel technologies, fossil fuel technologies become unprofitable. This policy creates a feedback response by which the cost of fossil fuels decrease. They then become more competitive than the subsidized renewable energies. Cases from both Japan and Germany demonstrated such market dynamics, despite massive resources spent to reduce carbon emissions. Climate mitigation policies have to be aligned consistently to support feed in tariff policy if they are to be effective. Moreover, very limited support and subsidies should be provided to fossil-fuel based power generators during the transition phase, until the share of renewable energy, as well as the infrastructural technologies, become more reliable and resilient. Furthermore, the fossil-fuel-based power generation market and fossil fuel investments should be monitored and controlled to limit the excessive increase in GHG emissions. Finally, the study investigated the role the nuclear option in the future energy mix and found that renewable energy options are far more cost effective and feasible than nuclear options when external costs (e.g. recovery from accidents, decommissioning, radioactive waste management for 10,000 years or so) of nuclear energy are included. This is not to mention the environmental hazard it poses and safety issues with international consequences. The study concluded that nuclear-free option is viable especially because Japan energy resources could sustain with no nuclear energy reactors running. Although one justification for nuclear energy is its reduction of carbon emissions, it has been argued that the largest share of carbon emissions is not caused by energy generation but rather by transportation, heating, and other sectors. Therefore, the emissions from fossil fuels are still less than the projected trends. Moreover, although nuclear energy is regarded as a zero-carbon energy source, it is found to be emitting hazardous GHG emissions. Consequently, in order to exploit the feed in tariff policy efficiently, the use of nuclear energy has to be strictly limited.

Further research should explore the impact of feed-in-tariff policy for achieving other objectives like green employment, local manufacturing, and the role it plays in industrial clusters. This is important to streamline and synergize policy-making efforts in order to produce more effective outcomes. Furthermore, quantitative assessment and integrated scorecards using comprehensive and updated market monitoring data about all policy-relevant aspects could improve the accuracy of the assessment results and lead to be better decision making.

(48589 words)

Appendices

Appendix A: Profitability Assessment Model

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.Control
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Simulation Control Parameters

(01) FINAL TIME = 360
Units: Month [120,360,120]
The final time for the simulation.

(02) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(03) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(04) TIME STEP = 0.0625
Units: Month [0,?]
The time step for the simulation.

****

(05) "1 kW Approximator"=
4.15
Units: Dmnl

(06) Administration Cost=
Regular Maintenance Cost*0.16
Units: Yen/kW

(07) "B/C Ratio"=
(Discounted Revenue/Discounted Cost)
Units: Dmnl
-1 is added to the formula to easily compare the result with PI

(08) Balance Sheet Check=
(Cash[System Price Choice]+Solar System Value[System Price Choice])-(Debt [System Price Choice]+Equity[System Price Choice])
Units: Yen

(09) Capital Cost=
Installments[System Price Choice]+Interest Payment[System Price Choice]+Maintenance Cost
[System Price Choice]
Units: Yen/Month

(10) Cash[System Price Choice]= INTEG (
Cash Inflow[System Price Choice]-Cash Outflow[System Price Choice]-Investment
[System Price Choice],
0)
Units: Yen

(11) Cash Inflow[System Price Choice]=
Solar Electricity Revenue[System Price Choice]+(Subsidy[System Price Choice
]+Downpayment[System Price Choice]+Loan amount
[System Price Choice])*per Month[System Price Choice]
Units: Yen/Month

(12) Cash Outflow[System Price Choice]=
Installments[System Price Choice]+Interest Payment[System Price Choice]+Maintenance Cost
[System Price Choice]
Units: Yen/Month

(13) Commercial Tax Rate=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,0,0.38/12)
Units: **undefined**
Source;
http://www.kpmg.com/global/en/services/tax/tax-tools-and-resource
s/pages/corporate-tax-rates-table.aspx

(14) Counter= INTEG (
Increment,
0)
Units: Dmnl

(15) DC to AC Conversion Loss=
0.77
Units: Dmnl

(16) Debt[System Price Choice]= INTEG (
Loan[System Price Choice]-Installments[System Price Choice],
0)
Units: Yen

(17) Depreciation Rate[System Price Choice]=
0.05
Units: 1/Month
((System Cost/System Life Time)/System Cost)

(18) Discounted Cost= INTEG (
Monthly Cost,
1e-12)
Units: Yen

(19) Discounted Electricity= INTEG (
LCOE Fraction,
0.0001)
Units: **undefined**

(20) Discounted Profit Fraction=
(Solar Electricity Revenue[System Price Choice]-Capital Cost)/(1+Interest Rate
[System Price Choice])^Counter
Units: Dmnl

(21) Discounted Revenue= INTEG (
Monthly Revenue,
1e-12)
Units: Yen

(22) Downpayment[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0, System Cost[System Price Choice
]*(1-Financing Fraction[System Price Choice
])*PULSE(1,1),0)
Units: Yen

(23) Equity[System Price Choice] = A FUNCTION OF(-Interest Payment,-Maintenance Cost
,-Monthly Depreciation,Solar Electricity Revenue,Subsidy)
Equity[System Price Choice]= INTEG (
(Subsidy[System Price Choice]+Solar Electricity Revenue[System Price Choice
])-(Maintenance Cost[System Price Choice]+Interest Payment
[System Price Choice]+Monthly Depreciation[System Price Choice]),
0)
Units: Yen

(24) Feed in Tariff=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice] = 0, Feed in Tariff for Residential Systems

(Time), Feed in Tariff for Non Residential Systems
(Time)
)
Units: Yen/kW

(25) Feed in Tariff for Non Residential Systems(
[(0,0)-(360,40)],(0,36),(240,36),(241,24),(360,24))
Units: Yen/kW

(26) Feed in Tariff for Residential Systems(
[(0,0)-(360,40)],(0,38),(120,38),(121,24),(360,24))
Units: Yen/kW

(27) Feed in Tariff Switch[System Price Choice]=
1
Units: Dmnl [0,1,1]

(28) Feed in Tariff Term=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,120,240)
Units: Dmnl

(29) Financing Fraction[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,0.75, 1)
Units: Dmnl [0.6,1,0.05]

(30) Fukuoka(
[(0,0)-(12,500)],(1,283),(2,338),(3,427),(4,462),(5,480),(6,392),(7,424),
(8,464),(9,402),(10,436),(11,326),(12,393))
Units: Dmnl

(31) Fukushima(
[(0,0)-(12,500)],(1,383),(2,393),(3,485),(4,482),(5,482),(6,423),(7,405),
(8,421),(9,342),(10,380),(11,337),(12,342))
Units: Dmnl

(32) Generated Electricity= INTEG (
Generating Electricity,
0)
Units: kW

(33) Generating Electricity=
IF THEN ELSE(Location Switch=0, Kyoto(Monthly Time),

IF THEN ELSE(Location Switch=1, Osaka(Monthly Time),
IF THEN ELSE(Location Switch=2, Tokyo(Monthly Time),
IF THEN ELSE(Location Switch=3, Fukuoka(Monthly Time),
IF THEN ELSE(Location Switch=4, Fukushima(Monthly Time),
IF THEN ELSE(Location Switch=5, Hokkaido(Monthly Time),
0))))))
*DC to AC Conversion Loss*System Size[System Price Choice]*Productivity Table (Time)/"1 kW Approximator"*per Month[System Price Choice]
Units: kW/Month

(34) Hokkaido(
[(0,0)-(12,500)],(1,253),(2,329),(3,467),(4,461),(5,500),(6,473),(7,450),(8,425),(9,374),(10,315),(11,186),(12,188))
Units: Dmnl

(35) Increment=
1/12
Units: 1/Month

(36) Installments[System Price Choice]=
IF THEN ELSE(Debt[System Price Choice]>0,System Cost[System Price Choice] /Loan term[System Price Choice],0)
Units: Yen/Month

(37) Interest Payment[System Price Choice]=
(Debt[System Price Choice]*Interest Rate[System Price Choice])/Months per Year [System Price Choice]
Units: Yen/Month

(38) Interest Rate[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,0.025,0.06)
Units: Dmnl

(39) Investment[System Price Choice]=
(Loan amount[System Price Choice]+Subsidy[System Price Choice]+Downpayment
[System Price Choice])*per Month[System Price Choice]
Units: Yen/Month

(40) IROR[System Price Choice]=
INTERNAL RATE OF RETURN(Net Cash Flow[System Price Choice] - Investment[
System Price Choice] , Months per Year[System Price Choice] , 0 , 0)
Units: Dmnl

(41) Kyoto([(1,300)-(12,500)],(1,315),(2,316),(3,408),(4,416),(5,456),(6,377),(7,388
),(8,436),(9,356),(10,380),(11,316),(12,313))
Units: Dmnl

(42) Land Development=
1500
Units: Yen/kW

(43) Land Rent=
Land Rent per kW*Land Size per kW/12
Units: Yen/kW

(44) Land Rent per kW=
150
Units: Yen/kW/m2

(45) Land Size per kW=
8.75
Units: m2

(46) LCOE=
Residential LCOE*(1/1-Commercial Tax Rate)
Units: **undefined**

(47) LCOE Fraction=
Generating Electricity/(1+Interest Rate[System Price Choice])^Counter
Units: **undefined**

(48) Loan[System Price Choice]=
Loan amount[System Price Choice]*per Month[System Price Choice]
Units: Yen/Month

(49) Loan amount[System Price Choice]=
((System Cost[System Price Choice]-Subsidy[System Price Choice])*Financing Fraction
[System Price Choice])*PULSE(1,1)
Units: Yen

(50) Loan term[System Price Choice]=
120

Units: Month

(51) Location Switch=
0
Units: Dmnl [0,5,1]
0 - Kyoto 1 - Osaka 2 - Tokyo 3- Fukuoka 4- Fukushima 5- Hokkaido

(52) Maintenance Cost[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,
Maintenance Cost for Residential Systems,
Simplified Unit Cost for Non Residential Systems
)
Units: Yen/Month
Maintenance Cost for Non Residential Systems

(53) Maintenance Cost for Non Residential Systems=
(Administration Cost+Regular Maintenance Cost+Maintenance Unit Cost for Non Residential Systems
*System Size[System Price Choice])/12
Units: Yen/kW

(54) Maintenance Cost for Residential Systems=
Maintenance Unit Cost for Residential Systems*System Size[System Price Choice
]
Units: Yen/kW

(55) Maintenance Unit Cost for Non Residential Systems=
Land Rent+Other Unit Costs for Non Residential Systems/12
Units: Yen/kW

(56) Maintenance Unit Cost for Residential Systems=
7400/12
Units: Yen/kW

(57) MIRR=
(IF THEN ELSE(Negative Cashflow Sum<>0, Positive CashFlow Sum/Negative Cashflow Sum
,1)^(1/Feed in Tariff Term))-1
Units: Dmnl

(58) Monthly Cost=
Capital Cost/(1+Interest Rate[System Price Choice])^Counter
Units: Yen/Month

(59) Monthly Depreciation[System Price Choice]=
Depreciation Rate[System Price Choice]*Solar System Value[System Price Choice
]
Units: Yen/Month

(60) Monthly Revenue=
Solar Electricity Revenue[System Price Choice]/(1+Interest Rate[System Price
Choice
])^Counter
Units: Yen/Month

(61) Monthly Time=
IF THEN ELSE(MODULO(Time, 12)=0,12,MODULO(Time, 12))
Units: Month

(62) Months per Year[System Price Choice]=
12
Units: Month

(63) Negative Cashflow=
IF THEN ELSE((Solar Electricity Revenue[System Price Choice]-Capital Cost)
>0, (Solar Electricity Revenue[System Price Choice]-Capital Cost),0)/(1+Interest Rate
[System Price Choice])^Counter
Units: Yen/Month

(64) Negative Cashflow Sum= INTEG (
Negative Cashflow,
1)
Units: Yen

(65) Net Cash Flow[System Price Choice]=
Cash Inflow[System Price Choice]-Cash Outflow[System Price Choice]
Units: Yen/Month

(66) NetPV= INTEG (
Present Value,
0)
Units: Yen

(67) Osaka(
[(1,300)-(12,500)],(1,331),(2,335),(3,425),(4,450),(5,469),(6,393),(7,430
),(8,463),(9,473),(10,381),(11,322),(12,330))
Units: Dmnl

(68) Other Unit Costs for Non Residential Systems=
Land Development+Personnel Expenses
Units: Yen/(kW*Month)

(69) per Month[System Price Choice]=
1
Units: 1/Month

(70) Personnel Expenses=
3000
Units: Yen/kW [1500,3000,1500]

(71) Positive Cashflow=
IF THEN ELSE((Solar Electricity Revenue[System Price Choice]>Capital Cost)
, (Solar Electricity Revenue[System Price Choice]-Capital Cost),0)*(1+Reinvestment Rate
)^(Feed in Tariff Term-Counter)
Units: Yen/Month

(72) Positive CashFlow Sum= INTEG (
Positive Cashflow,
0)
Units: Yen

(73) Present Value=
(Solar Electricity Revenue[System Price Choice]-Capital Cost)/(1+Interest Rate
[System Price Choice])^Counter
Units: Yen/Month

(74) Productivity Table(
[(0,0)-(360,1)],(0,1),(120,0.95),(240,0.8),(360,0.6))
Units: Dmnl

(75) Profitability Index=
NetPV/System Cost[System Price Choice]
Units: Dmnl

(76) Regular Maintenance Cost=
System Cost[System Price Choice]*Regular Maintenance Unit Cost
Units: Yen/kW

(77) Regular Maintenance Unit Cost=
0.014
Units: 1/kW

(78) Reinvestment Rate=
0.008
Units: Dmnl

(79) Residential LCOE=
Discounted Cost/Discounted Electricity
Units: Yen/kW

(80) Residential Subsidy per kW[System Price Choice]=
35000
Units: Yen/kW

(81) Sales Ratio=
0.8
Units: Dmnl [0,1,0.1]
Residential PV applications are required to consume the
generated electricity first, and they are allowed to sell only
the excess (surplus)余剰電気.

(82) Simplified Unit Cost for Non Residential Systems=
10000/12
Units: Yen/Month

(83) Solar Electricity Revenue[System Price Choice] = A FUNCTION OF(Feed in Tariff
,Feed in Tariff Switch,Generating Electricity,Sales Ratio,System Size)
Solar Electricity Revenue[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,
Feed in Tariff*Generating Electricity*Sales Ratio,
Feed in Tariff*Generating Electricity)
Units: Yen/Month

(84) Solar System Value[System Price Choice] = A FUNCTION OF(Investment,-
Monthly Depreciation)
Solar System Value[System Price Choice]= INTEG (
Monthly Investment[System Price Choice]-Monthly Depreciation[System Price Choice
],
0)
Units: Yen

(85) Subsidy[System Price Choice] = A FUNCTION OF(Feed in Tariff Switch, Residential Subsidy per kW
,System Size)
Subsidy[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0,

(Residential Subsidy per kW[System Price Choice]*System Size[System Price Choice
])*PULSE(1,1),
Non Residential Subsidy[System Price Choice]*PULSE(1,1)
)
Units: Yen

(86) System Cost[System Price Choice] = A FUNCTION OF(System Size,System Unit Cost
)
System Cost[System Price Choice]=
System Size[System Price Choice]*System Unit Cost[System Price Choice]
Units: Yen

(87) System Life Time[System Price Choice]=
360
Units: Month

(88) System Price Choice:
Choice 1, Choice 2, Choice 3
Choice 1, Choice 2, Choice 3

(89) System Size[System Price Choice]=
4
Units: kW

(90) System Unit Cost[System Price Choice]=
IF THEN ELSE(Feed in Tariff Switch[System Price Choice]=0, System Unit Cost of Residential Systems
[System Price Choice], System Unit Cost of Non Residential Systems[System Price Choice
])
Units: Yen/kW

(91) System Unit Cost of Non Residential Systems[System Price Choice]=
200000,250000,280000
Units: Yen/kW

(92) System Unit Cost of Residential Systems[System Price Choice]=
250000,350000,427000
Units: Yen/kW

(93) TNP Payback= INTEG (
Discounted Profit Fraction,
0)
Units: **undefined**

(94) Tokyo([(1,300)-(12,500)],(1,406),(2,387),(3,424),(4,432),(5,437),(6,339),(7,369
),(8,405),(9,305),(10,327),(11,313),(12,354))
Units: Dmnl

Appendix B: Dynamic Feed-in Tariff Price Adjustments Model

****
.Control
****

Simulation Control Parameters

(01) FINAL TIME = 300
Units: week
The final time for the simulation.

(02) INITIAL TIME = 0
Units: week
The initial time for the simulation.

(03) SAVEPER =
TIME STEP
Units: week [0,?]
The frequency with which output is stored.

(04) TIME STEP = 0.125
Units: week [0,?]
The time step for the simulation.

****

(05) "1 - increase in cost"=
step(1, 0)+step(0.5, Change Begins)-step(0.5, Change ends)
Units: Dmnl

(06) "2- decrease in cost"=
step(1, 0)-step(0.2,Change Begins)+step(0.2,Change ends)
Units: dmnl

(07) "3- Variable change"=
smooth3(random uniform(0,1,1),16)
Units: dmnl

(08) Annual operation time in hours=
900
Units: hour/year

(09) Annuity=
14.7
Units: dmnl

(10) Averaging time=
2
Units: week [2,16,2]

(11) Change=
if then else(Switch for response to cost change=0, 1,
if then else(Switch for response to cost change=1,"1 - increase in cost"
,
if then else(Switch for response to cost change=2, "2- decrease in cost",
"3- Variable change")))
Units: dmnl
Switch for testing the system response to change in cost. 0: no
change, 1: step increase, 2: step decrease, 3: variable change
using random parameter.

(12) Change Begins=
75
Units: week

(13) Change ends=
120
Units: week

(14) Deadline=
FIT Policy Term
Units: week

(15) Estimated cost=
parameter c*exp(parameter d*Operating Installations)
Units: euro/kW

(16) Estimated electricity generation per kW system per a year=
Annual operation time in hours*kW kWh/per year
Units: kWh/kW

(17) Estimated net electricity generation per kW system=
Annual operation time in hours*Facility lifetime in years*kW kWh
Units: kWh/kW
Annual operation time in hours*16*kW kWh

(18) Estimated net revenue=
Feed in Tariff Price*Estimated electricity generation per kW system per a year
*Annuity
Units: euro/kW

if then else(Time<260,900*20*FIT price, 900*20*Feed in tariff box*(1-anuity))

(19) Estimated Supply=
(parameter a*(Profit)-parameter b)
Units: kW/week
-399998x + 861573 954684*exp(-0.714*(Project cost/Quantity of approved projects)) param a*LN(Profit NPV)-param b supply rel(Profit NPV) if then else(switch three=0, (param a*Historical Profit)-param b, (param a*Profit NPV)-param b)

(20) Expected cost=
smooth(PV System cost, Averaging time)
Units: euro/kW

(21) Expected FIT=
Expected generation cost*(1+IRR)
Units: euro/kWh

(22) Expected generation cost=
((Expected cost+operation cost)/Estimated net electricity generation per kW system)
Units: euro/kWh

(23) Expected Installation= INTEG (
Expected Installation Rate-Installation rate,
initial capacity)
Units: kW

(24) Expected Installation Rate=
Estimated Supply*Normalization
Units: kW/week

(25) Expected Profit=
Expected Revenue-Expected cost
Units: euro/kW
DELAY3(Expected Revenue-Expected cost, 6)

(26) Expected Revenue=
Estimated electricity generation per kW system per a year*Expected FIT*Annuity
Units: euro/kW

(27) Facility lifetime in years=
20
Units: year

(28) Feed in Tariff Price=
if then else(Switch for Feed in tariff=0,Historical Feed in Tariff Price,
"FIT price (Continuous)")
Units: euro/kWh

(29) FIT Policy Term=
if then else(Time<=52, 52,
if then else(Time<78, 26,
if then else(Time<104, 13,
if then else(Time<156, 26,
if then else(Time<178, 13,4)))))
Units: week [4,52,4]
if then else(Time<24, 12, if then else(Time<60,6, 3))

(30) "FIT price (Continuous)"=
Generation cost+(Generation cost*IRR)
Units: euro/kWh
if then else(Time<260, Historical Feed in Tariff Price,
Generation cost+(Generation cost*IRR))

(31) Generation cost=
((PV System cost+operation cost)/Estimated net electricity generation per kW system
)
Units: euro/kWh
if then else(Time<261, Historical cost/estimated net electricity
generation per kW system, (Project cost+operation
cost)/estimated net electricity generation per kW system)

(32) Grid connection rate=
Installation before Connection/per week
Units: kW/week

(33) Grau model error margin=
Historical Installations-Thilo Grau Simulation
Units: kW/week

(34) Historical Feed in Tariff Price=
Historical Feed in Tariff Prices Table Function(Time)
Units: euro/kWh

(35) Historical Feed in Tariff Prices Table Function(
[(0,0)-(260,0.5)],(1.14,0.4),(2.836,0.4),(4.14,0.4),(5.444,0.4),(6.749,0.4
),(8.053,0.4),(9.357,0.4),(10.662,0.4),(11.966,0.4),(13.27,0.4),(14.575,0.4
),(15.879,0.4),(17.183,0.4),(18.488,0.4),(19.792,0.4),(21.096,0.4),(22.401

,0.4),(23.705,0.4),(25.009,0.4),(26.314,0.4),(27.618,0.4),(28.922,0.4),(30.227
,0.4),(31.531,0.4),(32.835,0.4),(34.14,0.4),(35.444,0.4),(36.748,0.4),(38.053
,0.4),(39.357,0.4),(40.661,0.4),(41.966,0.4),(43.27,0.4),(44.574,0.4),(45.879
,0.4),(47.183,0.4),(48.487,0.4))
Units: euro/kWh

(36) Historical Generation Cost=
((Historical PV System Cost*(1+operation cost percentage))/Estimated net electricity generation per kW system
)
Units: euro/kWh

(37) Historical Installation Table Function(
[(0,0)-(10,10)],(0.55,1337.84),(2.312,1832.1),(4.197,2700.32),(6.357,2709.19
),(8.216,5045.98),(10.043,6413.22),(10.834,10153.5),(12.167,12782.4),(13.88
,14271.6),(15.319,16711),(16.872,18896.4),(18.152,22055.5),(18.971,18521.9
),(19.719,22379.5),(21.523,23342.8),(23.314,26127.3),(24.667,29643.6),(26.578
,30577.3),(27.504,34723.6),(29.611,35266),(31.596,37545.8),(32.307,36820.8
),(33.54,38010.1),(34.204,38048.3))
Units: kW/week

(38) Historical Installations=
Historical Installation Table Function(Time)
Units: kW/week

(39) Historical Profit=
Profit Historical Data Table Function(Time)
Units: euro/kW

(40) Historical PV System Cost=
PV System Cost Historical Cost Data table function(Time)
Units: euro/kW

(41) initial capacity=
1
Units: kW

(42) Installation before Connection= INTEG (
Installation rate-Grid connection rate,
0)
Units: kW

(43) Installation rate=

(Expected Installation/project duration)*Probability effect
Units: kW/week

(44) IRR=
0.075
Units: Dmnl
Initial IRR*(1-(Installation/Goal))

(45) kW kWh=
1
Units: kWh/kW/hour

(46) Normalization=
Normalization effect table function(Estimated Supply)
Units: Dmnl

(47) Normalization effect table function(
[(0,0)-(1,1)],(0,0),(1,1))
Units: Dmnl

(48) Operating Installations= INTEG (
Grid connection rate,
0)
Units: kW

(49) operation cost=
PV System cost*operation cost percentage
Units: euro/kW

(50) operation cost percentage=
0.525
Units: Dmnl

(51) Our model error margin=
Historical Installations-Expected Installation Rate
Units: kW/week

(52) parameter a=
if then else(Time<52, 50, 50)
Units: (kW*kW)/(euro*week)

(53) parameter b=

890
Units: kW/week

(54) parameter c=
3813.9
Units: Dmnl

(55) parameter d=
-9e-08
Units: Dmnl

(56) per week=
1
Units: week

(57) per year=
1
Units: 1/year

(58) Probability effect=
Probability effect table function(Probability for developers to rush)*time effect
Units: Dmnl

(59) Probability effect table function(
[(0,0)-(1,2)],(0,0),(1,1.5))
Units: Dmnl

(60) Probability for developers to rush=
Profit/Expected Profit
Units: Dmnl

(61) Profit=
Estimated net revenue-PV System cost
Units: euro/kW
if then else(Time<261, estimated net revenue-Historical cost,)

(62) Profit Historical Data Table Function(
[(0,0)-(10,10)],(0,713.653),(0.381,708.541),(1.413,705.367),(2.089,709.263
),(3.101,713.653),(3.68,730.225),(4.104,757.845),(4.789,774.417),(5.464,777.389
),(6.477,774.417),(7.34,781.231),(8.164,807.561),(8.172,807.561),(9.852,821.324
),(9.852,826.895),(10.461,851.753),(10.677,881.968),(10.839,912.518),(10.995
,940.138),(11.157,967.758),(11.31,995.378),(11.54,1003.66),(13.03,1000.9),
(13.228,992.616),(14.626,1014.89),(14.915,1069.95),(14.917,1048.54),(15.036

,1078.24),(15.332,1105.86))
Units: euro/kW

(63) Project Cycle Time=
if then else(modulo(Time, FIT Policy Term)=0,0, modulo(Time, FIT Policy Term
))
Units: week

(64) project duration=
if then else(Switch for Feed in tariff=0, Remaining time to project duration relationship
(Remaining time before deadline),7)
Units: week

(65) PV System cost=
if then else(Switch System Cost=0, Historical PV System Cost, Estimated cost
)*Change
Units: euro/kW
The system cost can be either set to historical cost to validate
the model against the historical data using (Parameter
a*exp(Parameter b*Installations))*Change or to set it a
regression model to allow a feedback loop.

(66) PV System Cost Historical Cost Data table function(
[(0,0)-(10,10)],(0,4450.58),(4.345,4355.54),(7.702,4248.35),(11.23,4147.76
),(14.573,4055.46),(17.23,3917.05),(20.044,3799.95),(24.011,3799.71),(26.729
,3674.33),(30.236,3578.59),(33.834,3484.74),(36.758,3370.14),(40.405,3307.24
),(43.83,3209.85),(47.384,3290.63),(51.345,3317.85),(55.6,3286.05),(59.607
,3237.31),(63.841,3293.14),(67.06,3178.32),(71.286,3141.3),(75.101,3087.07
),(77.933,2972.14),(79,2796.54),(83.12,2832.05),(86.738,2759.57),(90.731,2745.62
),(94.651,2720.09),(98.856,2705.6),(103.008,2682.1),(106.973,2689.73),(110.503
,2594.71),(114.641,2556.14),(118.507,2594.75),(122.777,2580.65),(126.52,2503.87
),(130.241,2419.02),(134.184,2370.31),(138.464,2349.26),(142.296,2294.23),
(146.279,2258.15),(148.897,2133.99),(152.848,2122.08),(157.103,2157.65),(161.412
,2133.99),(165.443,2157.21),(169.061,2087.9),(172.962,2041.69),(177.089,2022.2
),(179.778,1892.72),(183.846,1867.74),(187.189,1777.7),(191.443,1751.96),(
195.394,1739.86),(199.415,1727.15),(203.599,1719.91),(207.696,1678.78),(211.805
,1647.96),(216.04,1642.17),(219.706,1712.92),(223.657,1728.51),(227.665,1711.67
),(231.558,1662.38),(235.509,1701.62),(239.46,1651.06),(243.41,1609.87),(247.756
,1585.8),(251.688,1621.68),(255.586,1561.71),(260,1536.65))
Units: euro/kW

(67) ratio of remaining time=
1-(Remaining time before deadline/Deadline)
Units: Dmnl

(68) Remaining time before deadline=
(Deadline-Project Cycle Time)
Units: week

(69) Remaining time to project duration relationship(
[(0,0)-(10,10)],(0,3),(4,7))
Units: week

(70) Switch for Feed in tariff=
1
Units: Dmnl [0,2,1]
0 : Discrete Feed in Tariff Price (Historical) 1 : Feed in
Tariff price (Continuous)

(71) Switch for response to cost change=
0
Units: Dmnl [0,3,1]
0 : No change 1 : Step increase 2 : Step decrease 3 : Variable
change using random uniform

(72) Switch System Cost=
1
Units: Dmnl [0,1,1]
0: Historical Cost 1: Estimated Cost using a regression model

(73) Thilo Grau Model Simulation Table Function(
[(0,0)-(174,10)],(0.556,431.617),(1.901,436.162),(3.023,407.593),(4.361,1466.2
),(5.616,1931.34),(6.835,1894.45),(8.133,3475.5),(9.302,4332.56),(10.543,5747.25)
Units: kW/week

(74) Thilo Grau Simulation=
Thilo Grau Model Simulation Table Function(Time)
Units: kW/week

(75) time effect=
if then else(Switch for Feed in tariff=0, time effect table function(ratio of remaining
time
), 1)
Units: Dmnl

(76) time effect table function(
[(0.5,0)-(1,1)],(0.5,0.25),(0.75,0.5),(1,1))
Units: Dmnl

Appendix C: Grid Capacity Planning for Renewable Energy Development Model

****
. Grid Capacity Planning for Renewable Energy Development Model
****

(01) Annual Grid Capacity Expansion=
Perceived Difference to Achieve Target Capacity for the Grid
Units: GW/Month

(02) Approved RE Applications= INTEG (
Monthly RE Applications-Project cancellation rate-Project Construction Rate
,
0)
Units: GW

(03) Available Grid Capacity= INTEG (
Monthly Increase in Grid Capacity+Grid Capacity Reuse Rate-Grid Connection Rate
,
5.6)
Units: GW

(04) Average time to shut down conventional energy plant=
2
Units: Month

(05) Averaging time=
3
Units: Month

(06) Capacity of Shutdown Conventional Energy= INTEG (
Shutting down rate,
0
)
Units: GW

(07) change in the stock=
Difference between stock level and the goal/Time to adjust stock level
Units: **undefined**

(08) Conventional Energy Capacity= INTEG (
-Shutting down rate,
initial capacity)
Units: GW

(09) Decision maker=
Decision maker table(Conventional Energy Capacity)
Units: Dmnl

(10) Decision maker table(
[(0,0)-(2,1)],(0,1),(0.9999,1),(1,0),(2,0))

Units: Dmnl

(11) Difference between stock level and the goal=
Goal-Stock
Units: **undefined**

(12) Difference to Achieve RE Capacity Target for RE=
RE Capacity Target-(Installed RE Capacity+Approved RE Applications)
Units: GW

(13) Difference to Achieve the RE Capacity Target for Grid=
RE Capacity Target-(Operating Grid Capacity for RE+Available Grid Capacity
)
Units: GW

(14) Goal=
10
Units: **undefined**

(15) Grid Capacity Reuse Rate=
min(max(Shutting down rate,0), Operating Grid Capacity for Nuclear Energy
/Average time to shut down conventional energy plant)
Units: GW/Month

(16) Grid Connection Rate=
max(min(Project Construction Rate, Available Grid Capacity/Time for Grid Connection
),0)
Units: GW/Month

(17) initial capacity=
40
Units: GW [0,40,40]

(18) Installed RE Capacity= INTEG (
Project Construction Rate,
0)
Units: GW

(19) Monthly Increase in Grid Capacity=
max(Annual Grid Capacity Expansion*Decision maker,0)/Time for Capacity Increase
Units: GW/Month
max(Annual Grid Capacity Expansion,0)

(20) Monthly RE Applications=
max(Perceived Difference to Achieve RE Capacity/Standard Time to Approve RE Application
,0)
Units: GW/Month
*sin(Time/5)

(21) Operating Grid Capacity=
Operating Grid Capacity for Nuclear Energy+Operating Grid Capacity for RE
Units: GW

(22) Operating Grid Capacity for Nuclear Energy= INTEG (
-Grid Capacity Reuse Rate,
Conventional Energy Capacity)
Units: GW

(23) Operating Grid Capacity for RE= INTEG (
Grid Connection Rate,
0)
Units: GW

(24) Perceived Difference to Achieve RE Capacity=
smooth(Difference to Achieve RE Capacity Target for RE, Averaging time)
Units: GW

(25) Perceived Difference to Achieve Target Capacity for the Grid=
smooth(Difference to Achieve the RE Capacity Target for Grid, Averaging time
)
Units: GW

(26) Project cancellation rate=
Approved RE Applications/Time to cancel project
Units: GW/Month

(27) Project Construction Rate=
min(max(Approved RE Applications,0), Available Grid Capacity)/Project Construction time
Units: GW/Month
min(max(Approved RE Applications,0), Available Grid
Capacity)/Project Construction time

(28) Project Construction time=
4
Units: Month

(29) RE Capacity Target=
Solar Energy Target Capacity Table Function(Time)
Units: GW

(30) Shutting down rate=
min(Approved RE Applications, Conventional Energy Capacity)/Average time to shut down conventional energy plant
Units: GW/Month

(31) Solar Energy Target Capacity Table Function(
[(2,0)-(26,70)],(0,1.805),(1,2.135),(2,3.329),(3,5.042),(4,6.91),(5,12.384
),(6,19.945),(7,20.26),(8,20.794),(9,21.438),(10,22.112),(11,22.77),(12,23.223

),(13,24.664),(14,26.052),(15,28.275),(16,31.115),(17,39.208),(18,65.442),
(19,68.158),(20,68.639),(21,68.776),(22,69.435),(23,69.339),(24,70))
Units: GW

(32) Standard Time to Approve RE Application=
2
Units: Month

(33) Stock= INTEG (
change in the stock,
0)
Units: **undefined**

(34) Time for Capacity Increase=
120
Units: Month [0,10,1]

(35) Time for Grid Connection=
1
Units: Month

(36) Time to adjust stock level=
2
Units: **undefined**

(37) Time to cancel project=
18
Units: Month

****
.Control
****

Simulation Control Parameters

(38) FINAL TIME = 120
Units: Month
The final time for the simulation.

(39) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(40) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(41) TIME STEP = 0.5
Units: Month [0,?]
The time step for the simulation.

****
.1112 grid capacity planning model
****

(01) Annual Grid Capacity Expansion=
Perceived Difference to Achieve Target Capacity for the Grid
Units: GW/Month

(02) Approved RE Applications= INTEG (
Monthly RE Applications-Project cancellation rate-Project Construction Rate
,
0)
Units: GW

(03) Available Grid Capacity= INTEG (
Monthly Increase in Grid Capacity+Grid Capacity Reuse Rate-Grid Connection Rate
,
5.6)
Units: GW

(04) Average time to shut down conventional energy plant=
2
Units: Month

(05) Averaging time=
3
Units: Month

(06) Capacity of Shutdown Conventional Energy= INTEG (
Shutting down rate,
0
)
Units: GW

(07) change in the stock=
Difference between stock level and the goal/Time to adjust stock level
Units: **undefined**

(08) Conventional Energy Capacity= INTEG (
-Shutting down rate,
inital capacity)
Units: GW

(09) Decision maker=
Decision maker table(Conventional Energy Capacity)
Units: Dmnl

(10) Decision maker table(
[(0,0)-(2,1)],(0,1),(0.9999,1),(1,0),(2,0))
Units: Dmnl

(11) Difference between stock level and the goal=
Goal-Stock
Units: **undefined**

(12) Difference to Achieve RE Capacity Target for RE=
RE Capacity Target-(Installed RE Capacity+Approved RE Applications)
Units: GW

(13) Difference to Achieve the RE Capacity Target for Grid=
RE Capacity Target-(Operating Grid Capacity for RE+Available Grid Capacity
)
Units: GW

(14) Goal=
10
Units: **undefined**

(15) Grid Capacity Reuse Rate=
min(max(Shutting down rate,0), Operating Grid Capacity for Nuclear Energy
/Average time to shut down conventional energy plant)
Units: GW/Month

(16) Grid Connection Rate=
max(min(Project Construction Rate, Available Grid Capacity/Time for Grid Connection
),0)
Units: GW/Month

(17) inital capacity=
40
Units: GW [0,40,40]

(18) Installed RE Capacity= INTEG (
Project Construction Rate,
0)
Units: GW

(19) Monthly Increase in Grid Capacity=
max(Annual Grid Capacity Expansion*Decision maker,0)/Time for Capacity Increase
Units: GW/Month
max(Annual Grid Capacity Expansion,0)

(20) Monthly RE Applications=
max(Perceived Difference to Achieve RE Capacity/Standard Time to Approve RE Application
,0)
Units: GW/Month
*sin(Time/5)

(21) Operating Grid Capacity=
Operating Grid Capacity for Nuclear Energy+Operating Grid Capacity for RE
Units: GW

(22) Operating Grid Capacity for Nuclear Energy= INTEG (
-Grid Capacity Reuse Rate,
Conventional Energy Capacity)
Units: GW

(23) Operating Grid Capacity for RE= INTEG (
Grid Connection Rate,
0)
Units: GW

(24) Perceived Difference to Achieve RE Capacity=
smooth(Difference to Achieve RE Capacity Target for RE, Averaging time)
Units: GW

(25) Perceived Difference to Achieve Target Capacity for the Grid=
smooth(Difference to Achieve the RE Capacity Target for Grid, Averaging time
)
Units: GW

(26) Project cancellation rate=
Approved RE Applications/Time to cancel project
Units: GW/Month

(27) Project Construction Rate=
min(max(Approved RE Applications,0), Available Grid Capacity)/Project Construction time
Units: GW/Month
min(max(Approved RE Applications,0), Available Grid
Capacity)/Project Construction time

(28) Project Construction time=
4
Units: Month

(29) RE Capacity Target=
Solar Energy Target Capacity Table Function(Time)
Units: GW

(30) Shutting down rate=
min(Approved RE Applications, Conventional Energy Capacity)/Average time to shut down conventional energy plant
Units: GW/Month

(31) Solar Energy Target Capacity Table Function(
[(2,0)-(26,70)],(0,1.805),(1,2.135),(2,3.329),(3,5.042),(4,6.91),(5,12.384
),(6,19.945),(7,20.26),(8,20.794),(9,21.438),(10,22.112),(11,22.77),(12,23.223
),(13,24.664),(14,26.052),(15,28.275),(16,31.115),(17,39.208),(18,65.442),

(19,68.158),(20,68.639),(21,68.776),(22,69.435),(23,69.339),(24,70))
Units: GW

(32) Standard Time to Approve RE Application=
2
Units: Month

(33) Stock= INTEG (
change in the stock,
0)
Units: **undefined**

(34) Time for Capacity Increase=
120
Units: Month [0,10,1]

(35) Time for Grid Connection=
1
Units: Month

(36) Time to adjust stock level=
2
Units: **undefined**

(37) Time to cancel project=
18
Units: Month

****
.Control
****

Simulation Control Parameters

(38) FINAL TIME = 120
Units: Month
The final time for the simulation.

(39) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(40) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(41) TIME STEP = 0.5
Units: Month [0,?]
The time step for the simulation.

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