# Trajectory of Renewable Energy Policies Depends on “Price Gap”: Learning from Photovoltaic Energy Policies Lead to “Grid Parity”

Yukihiko Nakata
Ritsumeikan Asia Pacific University, Graduate School of Management, Beppu, Oita, Japan

*Abstract*--**Renewable energies cloud reduces the GHG emissions. However, renewable energies have “price gap” of electricity between renewable energy and grid power. Thus, government policies are important to lead to “grid parity.” The renewable energy policies in Japan and Europe were analyzed. As the results, I found that the policies depend on the “price gap” between renewable energy and grid power. I propose “price gap” dependence model of the renewable energy policies. In the case of large “price gap”, the R&D support policy is most important to reduce the electricity price from the renewable energy and reduce the “price gap” as Japanese “Sunshine Project.” In the next step of middle “price gap”, “subsidy policy” and “net metering” are effective policies to enhance the renewable energy as the case of Japanese government and NEF. After the “price gap” ratio reduces to two or three, the Feed-in tariff (FiT) policy is most effective to lead to the “grid parity” as European and Japanese FiT. However, the “hard landing” FiT policy led PV market to shrink and exhaust in Europe. Thus, the important point of FiT policy is “soft landing” which smoothly leads to “grid parity” keeping the sustainable society, PV market and industry.**

## I. INTRODUCTION

Science and technology are foundations of nation’s competitiveness and the key to open up the future. Therefore, the science and technology policies are important. They need not only to enhance the nation’s competitiveness but also to protect the lives of citizens.

To protect the lives of citizens, the steady increase in global greenhouse gas (GHG) emissions must be reduced for environmental sustainability. One way to reduce GHG emissions is to use renewable energies.

However, in many cases, the costs of electricity produced by renewable energies are higher than that of grid power, which is mainly generated by using fossil fuels. Renewable energies have “price gap” of electricity between renewable energy and grid power. This means that most of the renewable energies have not yet achieved “grid parity.” Thus, government policies are important in order to lead to “grid parity.”

Japan implemented several incentive policies since it began researching and developing solar cells in 1955 and first applied them to a lighthouse. The "Sunshine Project" was launched in July 1974 following the first oil crisis in 1973 to promote R&D of solar cells. Japanese companies researched and developed many kind of solar cell technologies. As a result, Japanese companies became world leaders in the production of solar cells by the government policy [1].

Feed-in tariff (FiT) is a very effective policy mechanism designed to accelerate investment in renewable energy [1, 2]. The FiT obligate an electric power company to purchase the electric power which is generated by renewable energy at fixed price above market price during a fixed period at the installation time of the system. As the installation time becomes behind, this FiT price is reduced. Therefore, the FiT policy has the effect for investors to decrease the uncertainty and to encourage making an investment at an early stage. The electric power companies shift the additional cost above market price to all consumers and share the cost widely as the surcharge.

In fact, the FiT accelerated the investment in renewable energy and enhanced the instauration of renewable energy in Europe, such as Germany and Spain [3-6]. For example, photovoltaic (PV) system using solar cells rapidly installed in Germany and Spain. Then, it caused finally increase of a consumer burden and economical confusion because of rising of electricity prices and suppressing the PV market in Europe [3-6].

In Japan, the FiT for surplus electricity, which is a kind of the FiT, was introduced from November 1, 2009. This system buys the surplus electric power excluding self-consumption from the electric power from the solar cell at the about twice market price, and the domestic market was expanded more than twice as the result of that introduction.

Furthermore, the general FiT, in which the all electric power from renewable energy is bought at above market price, became effective from July 1st, 2012. Chairman of the FiT assessment committee has presented the FiT in April 25, 2012 [7]. It almost accepted the industrial request. Thus, many companies welcome the FiT. This means FiT price is high as same as Germany price of 2 years ago.

As described above, the renewable energy strongly depend on the policy because of the “price gap.”

Therefore, there is an awareness of the issues as follows.

What are appropriate renewable energy policies depending on the “price gap”?

How to lead to “grid parity” by FiT?

Thus, the trajectory of the renewable energy policies is analyzed from the viewpoint of the relations between policies and “price gap” to lead to “grid parity.”

## II. LITERATURE REVIEW

### *A. Literatures of Environmental Policy*

Nemet researched environmental policies from some viewpoints. Nemet et al. modeled the cost of 7 type’s carbon capture technology under various policy conditions to estimate the future costs [8]. Also, Nemet et al. evaluated the demand of subsidies versus R&D in case of organic PC technology, which is not currently commercially available [9]. As the research results, they found the cost does not reach the target when only subsidies, and not R&D, are implemented. This suggests that both subsidies and R&D are needed. In addition, he empirically examined public subsidies of emerging technology from wind power projects [10].As the results, even if firms learn from their experience, subsidies are still second best.

Nemet's former research suggests that environmental policies needs both R&D support and subsidies, and also firms efforts.

### *B. Literature Review of Photovoltaic Energy Policy*

Sarasa-Maestro et al. studied four major types of programs to encourage PV use: (1) FiT, (2) green certificates, (3) investment and tax incentive, and (4) bids on the quota system [11]. Avril et al. assessed the public support for PV for five countries (France, Germany, Japan, Spain, and US) from extensive policy review [12]. De La Hoz et al. analized the PV comparative policies in EU from economic analysis [13]. Uchida et al. studied the effects on policies on economy and environment to promote sustainable energies [14]. They used the simulation model combining a learning model and socio-economic model. They clarify the effect of policies on promotion of the residential PV system in Japan. Zhang et al. evaluated the impact of policy on diffusion of PV in Japan [15]. They used the data of 47 prefectures in Japan from 1996 to 2006. The empirical results show that the regional government policy clearly helps to promote PV system adoption. Also, they found that installation costs have a significant negative effect, and environmental awareness have a positive effect on PV system adoption at that time.

### *C. Literature Review of Feed-in Tariff*

Klein investigated different FiT designs applied in Europe to promote electricity generation from renewable energy sources and discussed two basic FiT designs including fixed FiTs, which are paid the fixed price above market price to generator during a fixed period, and premium FiTs, which are paid the added price based on the market price [1]. Also, the distribution of the costs was assessed [1]. Mendonça investigated FiT based on the cases of Europe and USA and mentioned the implementation of FiT design in the future [2].

Oshima analyzed the framework and characteristics of FiT in Germany and the reason for Germany success to promote the renewable energy by FiT policy [3]. Frondel etc. researched the problem of FiT in Germany and recommended the reduction of FiT [4], and argued the renewable energy policy in Germany and need to ensure a viable and cost-effective introduction of renewable energies into the country's energy portfolio [5]. Álvarez et al. analyzed the effects of FiT policy on employment from the case of the bubble which happened in Spain by the solar cell [6]. Couture et al. categorized FiT models and examined the advantages and disadvantages of different FiT models [16]. Yamaguchi researched the result and problem of Spain and Germany [17, 18]. Schallenberg compared fixed feed-in tariff and premium feed-in tariff based on Spain and clarified the advantage and the disadvantage [19]. Del Rio built a theoretical framework for dynamic efficiency analysis and assessed the dynamic efficiency properties of the different design elements of feed-in tariffs [20].

In addition, there are some simulation approaches to calculate the optimum FiT. Zahedi developed an economical model to determine a feed-in tariff for grid-connected solar PV electricity in Australia [21]. Wand et al. examined potential effects of Germany's FiT policy for small roof-top solar PV systems installed between 2009 and 2030 using simulation model [22].

Takehama analyzed the case of Germany and simulated the cost and the effect introducing into Japan [23]. Ayob et al. explored Japanese energy policies and develop simulation model to calculate the tariff for Japanese case [24].

Based on the above literature review, there are some researches environmental policies, photovoltaic energy policies and FiT focused on specific policies and specific countries in recent years. However, there is no research of the trajectory of photovoltaic energy policies over a long period of history.

## III. METHODOLOGY

Yin defines the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used [25].

In this paper, the case study method was taken to investigate a contemporary issue of the photovoltaic energy within its real-life context.

The research question is that what the appropriate trajectory of the renewable energy policies is over a long period of history. This research question is brake down into following two research questions.

What are appropriate renewable energy policies depending on the "price gap"?

How to lead to "grid parity" by FiT?

The case of photovoltaic energy policies in Japan was selected, because Japan is the pioneer of photovoltaic technology and has long history of photovoltaic policies after the "first oil crisis" in 1973. The case of photovoltaic energy policies in Japan is appropriate to research the trajectory of the renewable energy policies over a long period of history. The data was collected in the field researches at Kansai and Kyushu in Japan for case study. Also, the data of International Energy Agency (IEA), Japan Photovoltaic Energy Association (JPEA), Agency for Natural Resources and Energy in Japan and PV News etc. were collected and analyzed.

## IV. CURRENT SITUATION OF SOLAR CELL INDUSTRY

### *D. Solar Cell Production Amount*

The world solar cell production amount is rapidly increasing as shown in Fig. 1 [26]. The total amount has increased rapidly to 32.9 GW in 2011. But, it was slightly deceased to 31.9GW in 2012, because European PV market has shrank by FiT price reduction. Solar cell module production is around 35.5GW in 2012 [27].

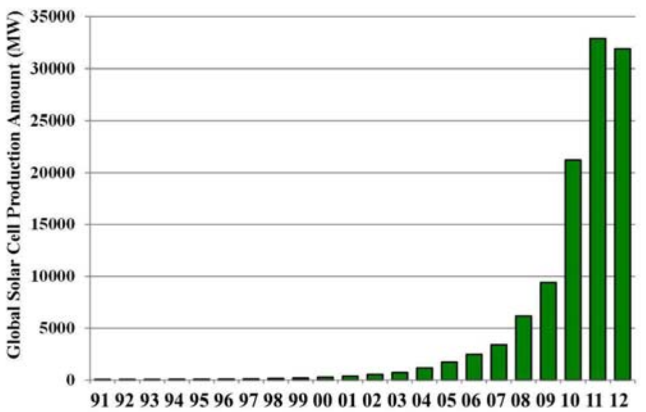


Fig. 1 World solar cell production amount (author made from [26]).

### *E. National Share of Solar Cell Production*

Figure 2 plots the changes in national share of solar cell production from 1997 to 2012 [26]. Japanese share reached a high point of about 50% in 2004. But, it fell to 6% in 2012 [26]. It may increase in 2013 [27].

Germany increased the share to 20 % in 2005 by introducing FiT. But, total European share reduced 3 % in 2012 [26], because of the bankrupt of Qcells in Germany.

China rapidly increased the share to 62% in 2011. But, It kept almost same 62% in 2012 [26], because of the bankrupt of Suntech power.

The U.S. share fell continuously from 40% in 1997 to 2% in 2012 [26]. Korea produced 770 MW in 2010 with 3% share [28].

In case of the installation of PV system per single fiscal year, Germany extracts Japan in 2004 by introduction of the FiT and rapidly increases the installation [29]. The installation in Germany is saturated and may reduce because of reduced FiT price.

Spain installed 2.75GW in 2008 by the FiT [29]. However the bubble burst and it was installed on almost single fiscal year. Same phenomenon resulted in Italy [29].

European PV market becomes to shrink by the reduced FiT price.

Instead of European Market, Japan, China and USA PV markets are rising up [29].

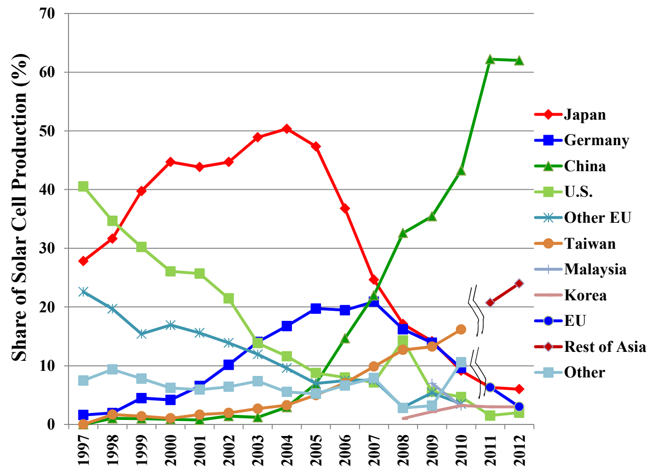


Fig. 2 National share of solar cell production (author made from [26])

## V. JAPANESE GOVERANMENT POLICYS IN EMBRYONIC STAGE

### *A. R&D Support Policy*

The world's first solar cell was invented by D. M. Chapin, C. S. Fuller and G. L. Pearson of Bell Laboratories in USA in 1954 [30]. They demonstrated that sunlight could be converted directly into electrical power with a conversion efficiency of about 6 % by using a p-n junction in single crystal silicon (Si).

Moreover, W. E. Spear and P. G. LeComber achieved the initial success of p-n control of an amorphous silicon in 1975 [31], and D.E. Carlson and C. R. Wronski of RCA developed the world's first amorphous solar cell with a conversion efficiency of 2.4 % in 1976 [32].

Japan began the R&D of the solar cell after the invention of the world's first solar cell, and the business has been started for a niche market of electric power supply at remote places, such as a radio relay station and a lighthouse.

However, the "first oil crisis" broke out in 1973 and the threat of the exhausted oil was exposed. And the "Sun Shine Project" was started by Japanese government in July, 1974 [33]. The R&D of the solar cell was done in order to alternate the usual electric power as one of the new energy sources. Its target is to reduce the price of 1/100.

By the "second oil crisis" in 1979, the "Sun Shine Project" was accelerated and the New Energy Development Organization (NEDO) was established in 1980.

To promote the diffusion of the solar cell, it is required not only the price reduction but also the exclusion of the obstacle by the government policy. It is the necessity to connect the solar cell system to the electric power grid cooperating with electric power companies to overcome the problem of the fluctuation of the sunlight and to reduce the battery cost. The experiment of the grid connection was conducted in Rokko Island from 1986. The Ministry of International Trade and Industry (MITI) relaxed the regulation of the photovoltaic system in 1990. The photovoltaic system can connect to the electric power grid and can sell the surplus electric power at the same price as an electricity-sales-to-utilities price.

*B. Subsidy Policy*

Moreover, the New Energy Foundation (NEF) began the "solar cell system monitor project for residences" as "subsidy system ", where will pay a subsidy for installation of the solar cell system for residences in 1994.

Thus, Japan was able to industrialize and promote the solar cell by the technical development and the supports from the Japanese government.

The Japanese government implemented programs to support various R&D projects and subsidized the installation of PV system. As a result, Japanese companies became world leaders in the production of solar cells with 50% production share in 2004 [26]. However, Japanese share is rapidly reducing after 2004 and to 17% of 2008 [26].

*C. Net Metering*

Japan took the system of “net metering” for promoting use of renewable energy sources. However, Japan brought back the subsidy as national policy in January 2009.

## VI. CASE STUDYS OF FIT IN EUROPE

Japanese share reached a high point of about 50% in 2004. But, it fell down rapidly, because Germany introduce FiT and increased the share to 20 % in 2005. Therefore, FiT in Europe was analyzed.

*A. Case Study of FiT in Spain*

The case of the FiT in Spain was researched [6, 17]. The installation of PV system in Spain was 12 MW in 2004 when the renewable energy promotion policy went into effect. This policy was not the FiT with fix price and determined the reference price based on the electricity prices. By this policy, PV system of less than100kW increased rapidly from 9 MW at the beginning of 2004 to 140 MW at the ends of 2006. Furthermore, in order to promote continuous and stable growth of PV system, a new government ordinance was gone into effect on June 1, 2007. The FiT was taken and the tariff, which is the purchase price of electric power, was fixed to 44 euro cent / kWh for under 100kW system and 41.75 euro cent/kWh for from 100kW to 10MW system, for 25 years. Especially the tariff of large-sized system was the steep raising from last 23.2 euro cent/kWh [17]. As a result, the targeted value of 371 MW in 2010 was expected to attain by October, 2007. For this reason, while pulling up the target by 2010 to 1200 MW in September, 2007. In addition, when the target was exceeded, the FiT price which goes into effect by the new government ordinance will be applied. Eventually, however, the all installation which signed up before September 30th, 2008, enjoyed the good conditions of the government ordinance in 2007, regardless of whether the goal of 1200 MW was met.

Although the fixed tariff after September 30th, 2008 was not determined, investors presumed that it will be less beneficial. The investor, thus, regardless of conversion efficiency, quality, etc. of a solar cell panel, but they perused the rapid installation as much power as possible before September 29th, 2008., fearing that the upcoming regulation would be much worse [6]. As the result, it expanded to 2934 MW by December, 2008. Especially the PV system of 100kW or more increased rapidly. According to the estimation by Álvarez etc., 100kW PV system would yield internal rates of return up to 17% in 2007, comparing to a 30 year Spanish bond is yield a return rate close to 5% per year [6]. It was in the overheating state from June, 2007 to September, 2008 just like "gold rush".

Although the electric power company is able to shift the additional cost of tariff on all consumers under the usual FiT, in the case of Spain, regulation of electricity prices for small-scale consumers remained substantially and those also had the high rate for the regulation [17]. For this reason, the electric power company could not completely shift the additional cost of tariff to the consumers, and then the deficit swelled [17]. Therefore, the government has to take stringent tight policy.

A new government ordinance became effective in September 26th, 2008 [17]. The fixed tariff of building installation reduced from 44 euro cent/kWh for 100kW system to 34 euro cent /kWh for under 20kW system, and 32 euro cent /kWh for over 20kW system. Moreover, maximum time limit to apply the fixed tariff was set in 2010 depending on the variety of the system [34]. Although the FiT oblige an electric power company to purchase the electricity by renewable energy during the fixed period at the fixed tariff, the interest rate which the investor was promised was substantially lowered by setting the maximum time limit. As a result, the bubble burst.

Thus, although a setup of the high fixed tariff which is separated from economic rationality looked to promote the introduction of the PV system in short-term from the case of Spain, it caused finally increase of a consumer burden and economical confusion because of rising of electricity prices and suppressing the PV market.

*B. Case Study of FiT in Germany*

Germany increased the PV installation as shown in Fig. 1 and solar cell production share as shown in Fig. 3 by the introduction of the FiT. However, Frondel [4] and Yamaguchi [18] have indicated that the problem is in cost effectiveness. This means although there was an effect in a numerical expansion, the FiT applied the high burden to the consumer by fixing the high fixed tariff over 20 years.

Transition of the fixed tariff of Germany is shown in Fig. 3 [35]. Although the rate of the fixed tariff decline was 5.3%/year from 2004 to the first half of 2010, after that it decrease rapidly at 26.6%/year because of stringent tight policy. Transition of the component price of PV system is shown in Fig. 4 [36]. The price of the solar cell module, which is a main component, fell from 3.32 euro/W in July, 2011 to 2.54 euro/W in June, 2010, and the rate of the decline is 20.1%/year.

This means that European FiT policy took "hard landing" which rapidly reduce FiT price to leads to "grid parity" destroying the sustainable PV market and industry.

The FiT is the policy mechanism to realize the self-sustainability of renewal energy until the grid parity which the electricity price by solar cell becomes the same as other power supplies, and to promote the innovation for the cost reduction. The rate of the fixed tariff decline should set as just over the rate of solar cell system price decline, like about 20%/year. Otherwise, it becomes impossible to achieve the original purpose.

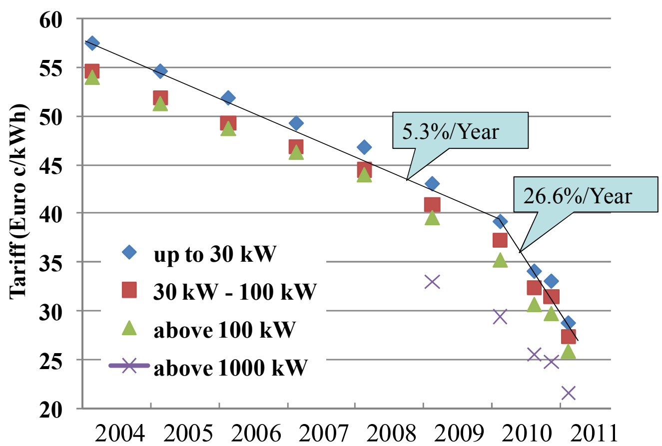


Fig. 3 Transition of the fixed tariff of Germany [35]

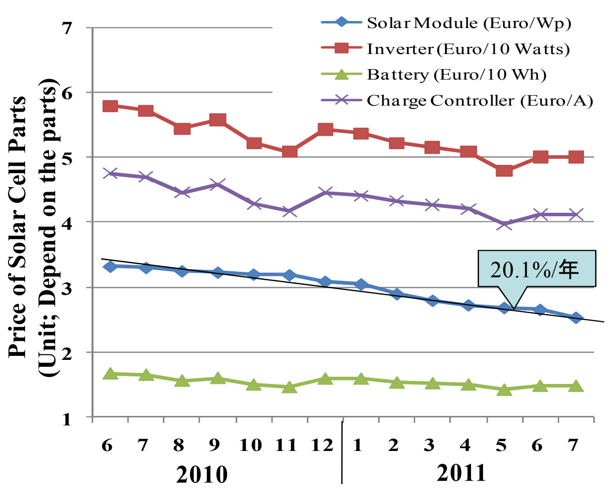


Fig. 4 Transition of component prices of PV system [36]

### C. *Current situation of European PV market.*

The FiT finally caused the increase of a consumer because of rising of electricity prices in Europe. Then, the FiT price reduced less than grid price [37]. The FiT policy was "hard landing" to the "grid parity" because the FiT price rapidly reduced to suppress the rising of electricity prices in Europe. As the results, the "hard landing" FiT policy led the European PV market become to shrink by reduced FiT price. European PV market has changed from "mega solar" to rooftop system for self-consumption [37].

## VII. JAPANESE GOVERANMENT POLICYS OF FIT

In case of the installation of PV system per single fiscal year, Germany extracts Japan in 2004 by introduction of the FiT and rapidly increases the installation [29]. Thus, Japan considered the introduction of FiT.

### A. *FiT for Surplus Electricity*

Although the subsidy program at a nation level to the PV system was terminated in Japan, the subsidy for household PV system under 10kW was revived in January, 2009. The amount of a subsidy was 70,000 yen per kW, and was reduced by the 48,000 yen from the 2011 fiscal year.

Moreover, the FiT for surplus electricity, which is a kind of a FiT, was introduced from November 1, 2009. This system applied to household use to buy the surplus electric power excluding self-consumption in the house from the electric power from the solar cell at 48 yen/ kWh, which is about twice price of the market price. Also, FiT of 24 yen /kWh was applied to the non-residences PV system over 10kW under 500kW [38]. This FiT for surplus electricity motivates the customer to save the electricity for household use to increase the surplus electricity than the ordinal FiT.

As the result of introduction of the FiT for surplus electricity and the subsidy, the Japanese domestic PV market was expand 400 MW per year in 2009 and 2010, as shown in Fig. 5 [39]. In case of Japan, PV system for household use is dominant and has 81.1% share and industrial use has 18.5% share in Japanese PV market in 2010 [39]. Incidentally, current electricity price is about 20 yen/kWh for household use and about 13 yen/kWh for industrial use in 2011.

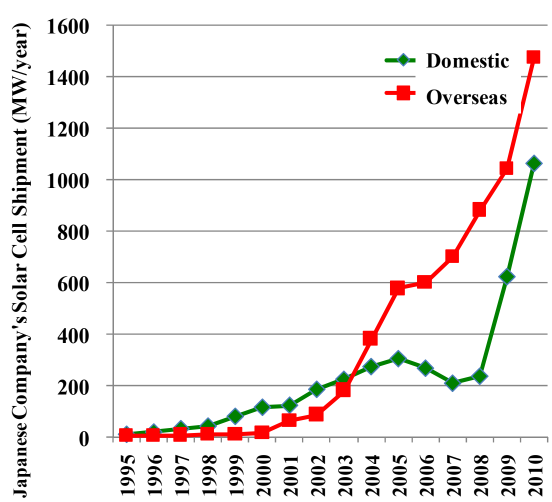


Fig. 5 Solar cell shipment of Japanese companies to domestic and overseas PV market [39].

As the common household PV system are mostly designed as self-consumption and surplus electric power with half-and-half in many cases. Therefore, the general FiT has about twice subsidy as compared with FiT for surplus electricity, if the purchase price is same. Thus, the general FiT is more effective than the FiT for surplus electricity to promote the installation of the PV system for household use.

## VIII. PRESENT FIT POLICY IN JAPAN

Japanese FiT of renewable energy was passed by Japan Diet in August 26, 2011 [38, 40]. This law obliges an electric power supplier to buy the electricity generated by the renewable energy sources (solar power, wind power, water power, geothermal power and biomass) at a fixed price during a fixed period. It become effective from July 1, 2012 [38]. All consumers pay the additional cost, which result from the purchase of the renewable energy at FiT by the electric power supplier, as the surcharge.

Although the FiT for surplus electricity applied only to the surplus electric power of PV system for household use, the new FiT was expanded to apply not only to solar power but also to wind power, water power, geothermal power and the biomass by this law. However, the FiT for PV household use was sustained the application to only surplus electric power as it was before.

The Minister of Economy, Trade and Industry (METI) give the notify of the FiT price and period, based on the opinions of the neutral independent FiT assessment committee, according to the classification of the source of renewable energy, an installation mode, a scale, etc. Moreover, to determine the FiT price, the law includes considering the profits of the supplier of renewable energy electricity for three years after the enforcement, in order to promote the renewable energy.

TABLE 1 FEED-IN TARIFF (FIT) OF JAPAN IN 2012 [7].

| Type of Energy | System Size | Feed-in Tariff (FiT): Committee Draft: Price (Yen/kwh) | Committee Draft: Period (year) | Industry Request: Price (Yen/kwh) | Remark |
|---|---|---|---|---|---|
| Solar | more than 10 kW | 42 | 20 | 42 | |
| | under 10 kW | 42 | 10 | | Surplus |
| Wind | more than 20 kW | 23.1 | 20 | 22～25 | |
| | under 20 kW | 57.75 | 20 | 50～55 | |
| Geothermal | more than $1.5x10^4$ kW | 27.3 | 15 | 25.8 (30MWclass) | |
| | under 1.5x $10^4$ kW | 42 | 15 | | |
| Hydro | 1x $10^3$ ～ $30x10^5$ kW | 25.2 | 20 | 24～34.06 | |
| | 200 ～ $1x10^3$ kW | 30.45 | 20 | | |
| | under 200 kW | 35.7 | 20 | | |
| Biomass | various types | 13.65～40.95 | 20 | 14.5～39 | |

The FiT assessment committee heared the requests from the renewable energy industries. Then, the chairman of the FiT assessment committee presented the FiT proposal in April 25, 2012 [7].

The FiT of Japan in 2012 is shown in Table 1. It almost accepted the industrial requests. Thus, many companies welcome the FiT. This means FiT price of PV is high as same as Germany price of 2 years ago as shown in Fig. 6. The FiT provides more incentives for investors as compared with the current FiT in Europe.

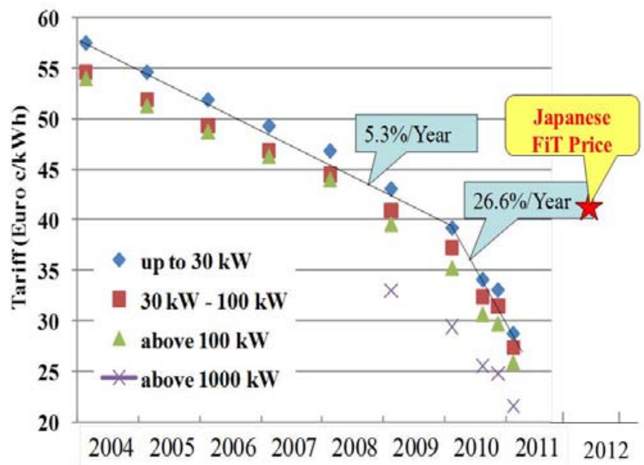


Fig. 6 Japanese FiT Price compared with Germany [35]

### B. *Accreditation of PV system*

To obtain the FiT, the renewable energy system needs to be accredited. The data of the accredited renewable energy system are published by Agency for Natural Resources and Energy in Japan [41].

The trend of accredited renewable energy systems was analyzed using the data of Agency for Natural Resources and Energy from July 2012 to May 2013 [41]. The change of accredited output power is shown in Fig. 7. To get the advantageous price, the accreditations of PV systems more than 1MW and 10 kW-1MW were rapidly increasing before the end of March of Japanese fiscal year. This means a lot of companies rush into the “last-minute” accreditations until the end of March 2013.

PV system has a monopoly on renewable energy with 99.9% of the accredited system numbers.

In the case of output, the output ratio of the accredited renewable energy system in March 2013 is shown in Fig 8. [41]. Total PV output accounts for 94.9%. It break down by 59.2% of the mega solar system 1MW or more, 29.4% of 10-1000kW and 6.4% of 10kW or less. Wind power accounted for 3.8%.

Solar cell output is accurately predictable from the solar radiation data. The environment assessment is less stringent.

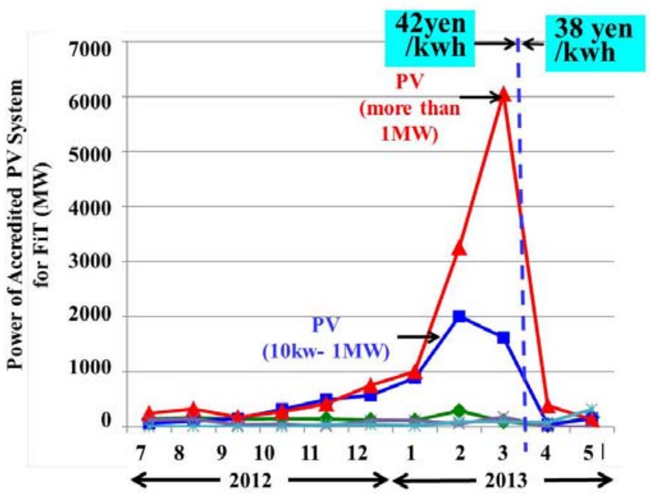


Fig. 7 Change of accreditation PV system power (author made from [41]).

In case of wind power, it is required the frequent data of wind speed. The environment assessment is strict. Therefore, it takes two or three years to prepare.

In case of geothermal and small hydro power, it takes a time for the investigation and the negotiations.

For this reason, in the first year, the PV system has monopoly. The other renewable energies are expected to grow in the following years.

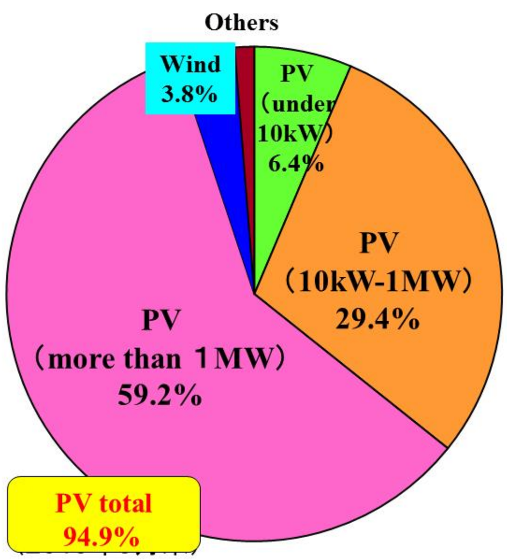


Fig. 8 Ratio of accredited total power in Japan (author made from [41]).

*A. Effect of Expanded Japanese PV market*

After getting the accreditation, PV system is constructed buying the solar panels.

Figure 9 shows the total shipment of solar cell by Japanese PV companies [42]. The PV domestic shipments expand from 1400GW in 2011 to 3800GW in 2012. It is 2.7 times increase from the previous year. This large increase of PV shipments comes of the effect of the FiT.

PV export shipments are reduced from 1281GW in 2011 to 562GW in 2012 because European PV market has been shrunk [40].

This is the clear evidence that the FiT expand Japanese PV market.

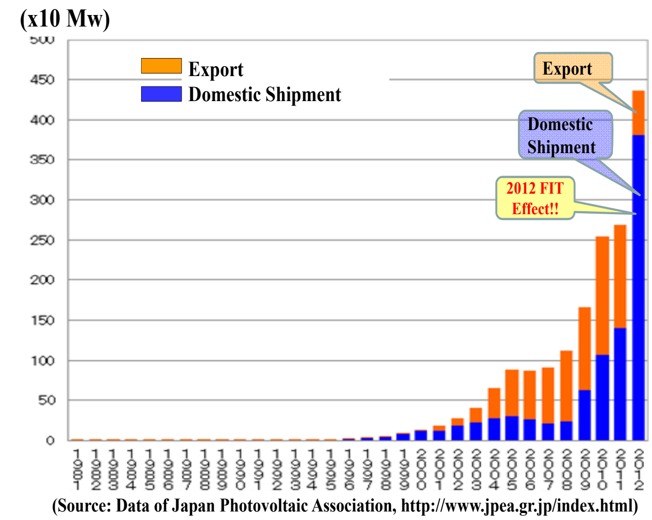


Fig. 9 Total Shipment of Solar Cell by Japanese PV Companies [42]

## IX. PROPOSAL OF "PRICE GAP" DEPENDENCE MODEL

As the analysis results of the renewable energy policies in Japan and Europe, I found that the policies depend on the "price gap" of electricity between renewable energy and grid power. Thus, I propose "price gap" dependence model of the renewable energy policy, which is shown in Fig. 10.

The "price gap" ratio is defined by the ratio of electricity price of renewable energy to it of the grid power. Thus, the high "price gap" ratio means that electricity price of renewable energy is expensive.

At the start of Japanese "Sunshine Project" in 1972, the solar cell price was about 20,000 yen/W [43]. The target of "Sunshine project" was set 100 – 200 yen/W of the solar cell price in around 2000 price. This means the "price gap" ratio is about 100 - 200. Thus, in the case of large "price gap", the R&D support policy is most important to reduce the "price gap" as shown in the "R&D policy range" of Fig. 10, as Japanese "Sunshine Project". This R&D support policy carried on into "New Sunshine Project" from 1993. Also, NEDO established PV roadmap toward 2030 named "PV2030" and revised it as "PV2030+" [44]. They set the targets of "grid parity" for household use of 23 yen/kWh and the target of "grid parity" for industrial use of 14 yen/kWh. This paper uses the "grid parity" for household use in the usual cases. "PV2030" and "PV2030+" were including the R&D projects to reach the both "grid parities".

Therefore, under the "price gap" ratio of about 100, the "R&D policy" is the dominant policy as shown in the "R&D policy range" of Fig. 10.

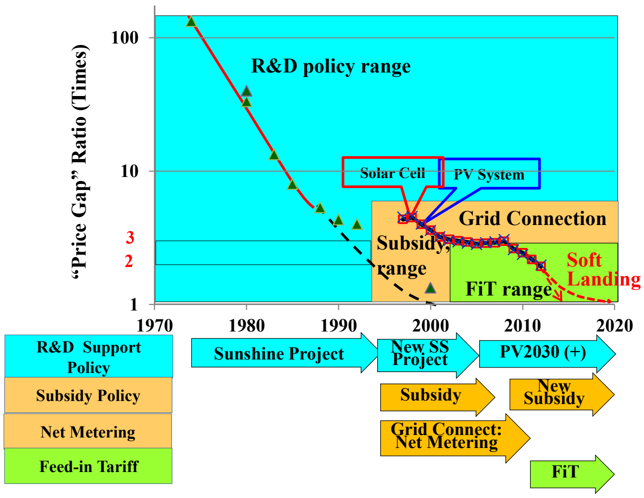


Fig. 10 "Price gap" dependence model of renewable energy policy

NEF began the "solar cell system monitor project for residences" as "subsidy system" from 1994 to 1996. But, the new subsidy was resumed again from 2008 [45]. The new subsidy was terminated at March 31, 2014, because FiT was introduced.

Also, MITI relaxed the regulation of the photovoltaic system in 1990. The photovoltaic system can connect to the electric power grid and can sell the surplus electric power at the same price as an electricity-sales-to-utilities price, which is "net metering"

Therefore, in the next range of middle "price gap" under about 5, "subsidy policy" and "net metering" after grid connection were effective policies to enhance the renewable energy as Japanese government and NEF as shown in the "Grid Connection and Subsidy range" of Fig. 10.

After the "price gap" ratio reduces to two or three, the FiT policy is possible to introduce because the FiT price is generally about two or three times of grid power price. Thus, after the "price gap" ratio reduces to two or three, the FiT policy is most effective policy using the market mechanism to lead to the "grid parity" as European and Japanese FiT.

Therefore, under the "price gap" ratio of two or three, the FiT policy is the most effective policy as shown in the "FiT policy range" of Fig. 10.

Through the use of the "price gap" dependence model, I verified that the policies depend on the "price gap". The "price gap" dependence model is very useful to research and evaluate the renewable energy policies.

On the other hand, European FiT took the rapid reduction to suppress the rapid increasing of the electricity price. Then, European PV market shrank and exhausted by the rapid reduction of FiT price. I named it "hard landing" FiT policy.

According to the "price gap" dependence model, the "price gap" ratio has reduced from about 100 to less than 2 by the many efforts. The "price gap" ratio has to reach to one for environmental sustainability. The important point of FiT policy is "soft landing" which smoothly leads to "grid parity" as shown in Fig. 10 after learning from European FiT experience. The "soft landing" will keep the sustainable society, PV market and industry. According to the "price gap" dependence model, the "soft landing FiT policy" is most expected policy in the final stage.

## X. CONCLUSIONS

Renewable energies have "price gap" of electricity between renewable energy and grid power. Thus, government policies are important in order to lead to "grid parity." The renewable energy policies in Japan and Europe were analyzed to clarify the relations between policies and "price gap".

As the results, I found that the policies depend on the "price gap" of electricity between renewable energy and grid power. Thus, I propose "price gap" dependence model of the renewable energy policy.

Under the "price gap" ratio of about 100, the "R&D policy" is most important and dominant to reduce the electricity price from the renewable energy and reduce the "price gap" as Japanese "Sunshine Project."

In the next range of middle "price gap" under about 5, "subsidy policy" and "net metering" after grid connection were effective policies to enhance the renewable energy as Japanese government and NEF.

Under the "price gap" ratio of two or three, the FiT policy is the most effective policy as Europe and Japan.

Through the use of the "price gap" dependence model, I verified that the policies depend on the "price gap". The "price gap" dependence model is very useful to research and evaluate the renewable energy policies.

In addition, the "soft landing" FiT policy, which smoothly leads to "grid parity", is important to keep the sustainable society, PV market and industry in the final stage after learning from European FiT experience.

## ACKNOWLEDGMENTS

I express my appreciation for financial support from Tohoku University as "Regional Industry Reconstruction Research Program."

## REFERENCES

[1] Arne Klein, "Feed-in Tariff Designs: Options to Support Electricity Generation from Renewable Energy Sources," VDM Verlag Dr. Müller, 2008.

[2] Miguel Mendonça, "Feed-in Tariffs: Accelerating the Development of Renewable Energy", Earthscan, 2007.

[3] Kenichi Oshima,; "German Expediencies to promote Renewable Energy – Framework and Fact of Feed-in tariff - (Japanese)," Ritsumeikan University human sciences research institute bulletin, No. 88, and p65-91, 2007.

[4] Manuel Frondel, Nolan Ritter, Christoph M. Schmidt, "Germany's solar cell promotion: Dark clouds on the horizon", Energy Policy, vol.36, pp. 4198-4204, 2008.

[5] Manuel Frondel, Nolan Ritter, Christoph M. Schmidt, Colin Vance, "Economic impacts from the promotion of renewable energy technologies: The German experience" Energy Policy, vol.38, pp. 4048-4056, 2010.

[6] Gabriel Calzada Álvarez, Raquel Merino Jara, Juan Ramón Rallo Julián , José Ignacio García Bielsa "Study of the effects on employment of public aid to renewable energy sources" PROCESOS DE MERCADO, Vol.VII, No.1, p1-14, 2010.
[7] Chairman's draft of Feed-in Tariff assessment committee of Ministry of Economy, Trade and Industry (Japanese), Available in http://www.meti.go.jp/committee/chotatsu_kakaku/006_haifu.html
[8] Gregory Nemet, Erin Baker and Karen Jenni, "Modeling the future costs of carbon capture using experts' elicited probabilities under policy scenarios", *Energy.* Vol. 56, p218-228, Jul 2013.
[9] Gregory Nemet, Erin Baker, "Demand Subsidies versus R&D: Comparing the Uncertain Impacts of Policy on a Pre-commercial Low-Carbon Energy Technology", *Energy Journal* , Vol. 30, Issue 4, p 49-80, 2009.
[10] Gregory Nemet, "Subsidies for New Technologies and Knowledge Spillovers from Learning by Doing", *Journal of Policy Analysis & Management*, Vol. 31 Issue 3, p601-622, Summer 2012.
[11] Carlos J. Sarasa-Maestro. Rodolfo Dufo-Lopez, Jose L.Bernal-Agustin, "Photovoltaic Remuneration Policies in the European Union", *Energy Policy*, vol. 55, Issue. 1, p 317-28, April 2013
[12] S. Avril., C. Mansilla., M. Busson. T. Lemaire, "Photovoltaic Energy Policy: Financial Estimation and Performance Comparison of the Public Support in Five Representative Countries', *Energy Policy*, Vol.. 51, Issue 1, p. 244-58, December 2012.
[13] Jordi de la Hoz, Helena Martin, Blanca Martins, Jose Matas, Josep Maria Guerrero, "Economic Analysis of Different Supporting Policies for the Production of Electrical Energy by Solar Photovoltaics in Western European Union Countries", *Energy Policy*, Vol. 48, Issue 1, p 846-49, September 2012.
[14] Susumu Uchida, Yoshiro Higano, "Comprehensive Evaluation of a Promotion Policy for the Residential Photovoltaic Industry Considering the Cycle of Learning and the Environmental Value", *Studies in Regional Science,* Vol. 40, Issue. 2, p 277-92, 2010. (In Japanese. With English summary.)
[15] Yu Zhang, Junghyun Song, Shigeyuki Hamori, "Impact of Subsidy Policies on Diffusion of Photovoltaic Power Generation", *Energy Policy,* Vol. 39, Issue 4, pp. 1958-64, April 2011.
[16] Couture, Toby, Yves Gagnon,; "An Analysis of Feed-in Tariff Remuneration Models: Implication for Renewable Energy Investment," Energy Policy, vol. 38, pp. 955-965, 2010.
[17] Mitsutsune Yamaguchi (Japanese) "Spain's Photovoltaic Experience –Light and Shadow", Nikkei Business Publications net ECO JAPAN, April 8, 2011, World Wide Web, http://eco.nikkeibp.co.jp/article/column/20110406/106293/?P = 1
[18] Mitsutsune Yamaguchi (Japanese) "German Photovoltaic advised Policy Change by IEA" Nikkei Business Publications net ECO JAPAN, April 25th, 2011, World Wide Web, http://eco.nikkeibp.co.jp/article/column/20110420/106392/
[19] Schallenberg-Rodriguez, Julieta; "Fixed feed-in tariff versus premium: A review of the current Spanish system," Renewable and Sustainable Energy Reviews, vol. 16, pp. 293-305, 2012.
[20] Pablo del Rio,; "The Dynamic Efficiency of Feed-in Tariffs: The Impact of Different Design Elements," Energy Policy, vol. 41, pp. 139-151,2012.
[21] Zahedi, Ahmad; "Development of an economical model to determine an appropriate feed-in tariff for grid-connected solar PV electricity in all states of Australia," Renewable and Sustainable Energy Reviews, vol. 13, pp. 871-878, 2009.
[22] Wand, Robert,; "Feed-in Tariff for photovoltaics: Learning by doing in Germany?" Vol. 88, pp. 4387-4399, 2011.
[23] Asami Takehama,; "the Feed-in Tariff introduction scenario to household photovoltaic towards low carbon social (Japanese)", Policy Science, vol. 17, special issue, pp. 93-123, 2010.
[24] Ayoub, Nasser, Yuji Naka,; "Governmental intervention approach to promote renewable energies-Special emphasis on Japanese feed-in tariff," Energy Policy, vol. 43, pp. 191-201, 2012.
[25] Yin, R. K. (1984). *Case study research: Design and methods*. Newbury Park, CA: Sage.
[26] PV News, May and April 2008, May 2010, May 2011, May 2012 and Mat 2013.
[27] IHS, re-quote from The Nikkei (Newspaper) 30 July, 2013
[28] Kyung-Hoon Yoon "National Survey Report of PV Power Application in Korea 2010", World Wide Web, International Energy Agency (IEA) , http://www.iea-pvps.org/index.php?id=146.
[29] International Energy Agency, Trends in Photovoltaic Applications", Report of IEA-PVPS) T1-21, 2012
[30] D. M. Chapin, C. S. Fuller, G. L. Pearson, "A new silicon p-n junction photocell for converting solar radiation into electric power", J. Appl. Phys. Vol. 25, pp. 676, 1954
[31] W. E. Spear and P. G. LeComber , *Solid State Commun*, Vol. 17, pp. 1198, 1975.
[32] D. E. Carlson and C. R. Wronski, "Amorphous Silicon Solar Cell", Appl. Phys. Lett. Vol. 28, pp. 671 - 673, 1976.
[33] New Energy and Industrial Technology Development Organization (NEDO), "Why did Japan get the world's No.1 in the solar cell?" (Japanese) NEDOBOOKS,s 2007
[34] Emma Hughes "Spanish Government cuts solar subsidies for new and existing plants", PV-Tech 06 January 2011, World Wide Web, http://www.pv-tech.org/news/print/spanish_government_cuts_solar_subsidies_for_new_and_existing_plants
[35] Lothar Wissing and "National Survey Report of PV Power Applications in Germany 2010," World Wide Web, http://www.google.co.jp/search?hl=ja&source=hp&q=National+Survey+Report+of+PV+Power+Applications+in+Germany+2010&rlz=1R2ADRA_jaJP443&aq=f&aqi=&aql=&oq=
[36] Solarbuzz Home page, "Solarbuzz Retail Pricing," World Wide Web, http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices
[37] Valérick Cassagne, "How self-consumption could reshape rooftop market", Proceeding of EU PVSEC 2013, Parc des Expositions Paris Nord Villepinte, Conference 30 September to 04 October 2013
[38] Agency of Natural Resources and Energy, Committee report of Feed-in Tariff (Japanese) "Detail design of Feed-in Tariff for renewable energy", February 18th, 2011., World Wide Web, http://www.meti.go.jp/committee/summary/0004601/houkokusho_110218_01.pdf
[39] Japan Photovoltaic Energy Association Homepage "Transition of solar cell shipment in Japan", World Wide Web, http://www.jpea.gr.jp/pdf/qlg2010.pdf
[40] Agency of Natural Resources and Energy, "FiT of renewable energy", August, 2011, World Wide Web, http://www.enecho.meti.go.jp/saiene/kaitori/2011kaitori_gaiyo.pdf
[41] Agency of Natural Resources and Energy, "Status of Accredited Renewable Energy System", End of February, 2013, World Wide Web, http://www.enecho.meti.go.jp/saiene/kaitori/index.html#setsubi
[42] Japan Photovoltaic Energy Association (JPEA), "Shipment of solar cell in Japan", http://www.jpea.gr.jp/document/figure/index.html
[43] Agency for Natural Resources and Energy, "1999/2000 Resources and Energy Yearbook", International Trade and Industry Materials Research Council, January 1999, (Japanese)
[44] New Energy and Industrial Technology Development Organization, "PV Roadmap (PV2030+)", June, 2009.
[45] Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, "Survey on prevalence trends in PV systems," Contractors: RTS Corporation, February 2013