Master's Thesis

Estimation of Diffusion and Adoption of Solar PV Technology in Japan and Germany: Prospects for Tanzania

By

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Certification

I, **<u>OMARY, Haji Rehani</u>** hereby declare that the contents of this Master's Thesis are original and true, and have not been submitted at any other university or educational institution for the award of degree or diploma.

All the information derived from other published or unpublished sources has been cited and acknowledged appropriately.

OMARY, Haji Rehani

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List of Abbreviations

Abbreviation	Definition
BIPV	Building Integrated Photovoltaic
BOS	Balance of System
EWURA	Energy and Water Utilities Regulatory Authority
IEA	International Energy Agency
JPEA	Japan Photovoltaic Energy Association
METI	Ministry of Economy, Trade, and Industry
PVPS	Photovoltaic Power Systems Programme
REA	Renewable Energy Authority
REF	Renewable Energy Fund
TANESCO	Tanzania Electric Supply Company
TAREA	Tanzania Renewable Energy Agency
VETA	Vocational Education Training Authority

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Abstract

This research studied the evolution of solar PV technology in Tanzania, Japan and Germany by holistically looking into the dynamics of their technological innovation systems (TIS) for solar PV. The dynamics of the TIS for all the countries involved assessing the key actors and major interactions in the system. The research also attempted to look into the major historical events occurred from the first engagement of solar related activities in the country. Analyzing the TIS in a systemic way is vital in understanding the building blocks of each system which in turn will help measuring its performance as well as identifying major differences between the three systems.

As a mean to mitigate energy poverty in least developed countries, unlike developed countries such as Japan and Germany, the adoption of renewable energy technologies had faced a number of drawbacks to advance to higher paradigms. This prompted the need to analyze the problem in a holistic and systemic way in which the concept of technological innovation system plays an important role to help the analysis. In the field of national systems of innovation research more efforts have been on studying solar PV technological innovation system for developing countries such as Japan and Germany with a neglected efforts on least developed countries "follower-countries". The estimation of diffusion and adoption of solar PV technology for Japan and Germany was analyzed using two approaches, S-curve models and the technological innovation system (TIS). The results shows that the logistic model adequately explains the diffusion of solar PV systems in both Japan and German and can be used to estimate the diffusion curves not only solar PV technology in the context of developed countries but also least developed ones. The results of the models estimations have shown that the government can influence the diffusion curve in the case of solar PV technology

unlike other consumer products which only words of mouth can lead to a diffusion in the social system. This research also showed how strong institutional infrastructure facilitated the growth of solar PV in Japan and Germany.

The findings of this research will give insights to key decision makers on possible issues that may contribute to fall-out of the system and help Tanzania accelerate its electrifications by drawing lessons from Japan and Germany.

1 INTRODUCTION

1.1 Overview and Motivation

Technological advances in the world has led to economic developments but coming together with the cost of environmental pollutions such as greenhouse gas emissions as well as some countries being poorer than others. Around the globe a big population of about 1.4 billion living in energy poverty without the access of electricity for basic needs such as cooking an lighting (LightingAfrica, 2018), of those people, most are living in South Asian and African countries.

In most of African countries where energy poverty is s pressing challenge, there is a huge market potential for adopting solar systems for both residential and public use. Despite the strong push by governments and international organizations to shift from using conversional sources of energy to more clean one, the adoption rate has been very minimal (Kebede & Mitsufuji, 2007). There is a great deal of barriers to the adoption of renewable energy systems and shifting from using conventional sources of energy to clean energy has been a long term challenge in most developing countries such as Tanzania[1], Ethiopia, Kenya and Zambia.

As a mean to mitigate energy poverty in least developed countries, unlike developed countries such as Japan and Germany, the adoption of renewable energy technologies had faced a number of drawbacks to advance to higher paradigms. This bring the need to analyze the problem in a holistic and systemic way in which the concept of technological innovation system plays an important role to help the analysis.

[1] The power plan-2040 shows a small role of renewable energy technologies and more on fossil fuels dependence

In this national systems of innovation research field more efforts have been on studying solar PV technological innovation system for developed countries such as Japan and Germany with a neglected efforts on least developed countries “follower-countries”[2]. This bring the need to contribute to field by studying the evolution of solar PV technology in the context of a follower-country Tanzania.

1.2 Japan Renewable Energy

Japan has the national average irradiation received at ground level is estimated at 5.2 kWh/m2 per day, between 2000 and 2007 Japan was a powerhouse in manufacturing of solar photovoltaics and in installation of PV systems (*Figure 1-2*). The solar irradiation varies from 4.55 kWh/m2 per day to about 6.25 kWh/m2 per day (SolarGIS, 2019). Due to lack of natural resources such as oil and natural gas, Japan depends on natural fuels i.e. oil, coal and liquefied natural gas imported from abroad[3] (see Figure 1-5, Figure 1-3). Years after the 2011-great earthquake in Fukushima, japan had been experiencing a falling-off of energy self-sufficiency ratio[4] (see *Figure 1-4*), an increase in electric power generation costs and emission of greenhouse gases (METI, 2016). In order to increase Japan’s energy self-sufficient ratio, reduce import of coal, CO_2 emissions, renewable energy generation had been put forward (*Figure 1-6*).

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[2] TIS study for Ethiopia have been conducted but in the context of system functions and historical events but unlike that study this research aims at elements of TIS and historical events

[3] In 2016, 86% of crude oil came from Middle East such as Saudi Arabia or United Arab Emirates. Due to unstable political conditions in middle east, this affect Japan’s energy situation

[4] Japan ranked 33th in 2015 compared to other OECD countries (METI, 2016)

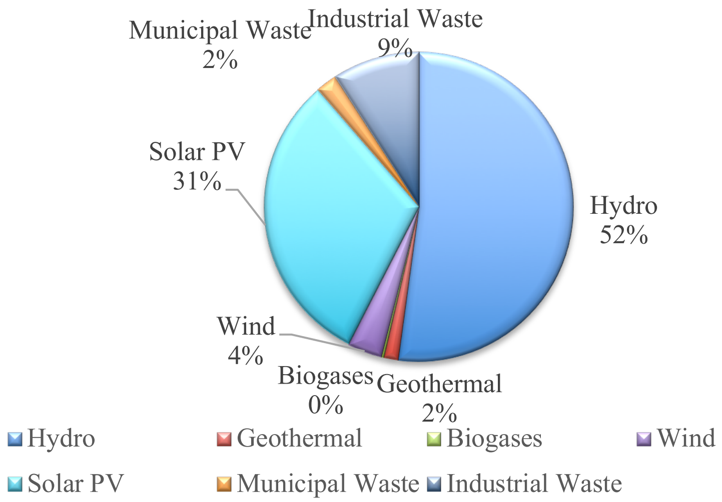


Figure 1-1.Share of sources in renewable electricity generation – Japan

Source: (METI, 2016)

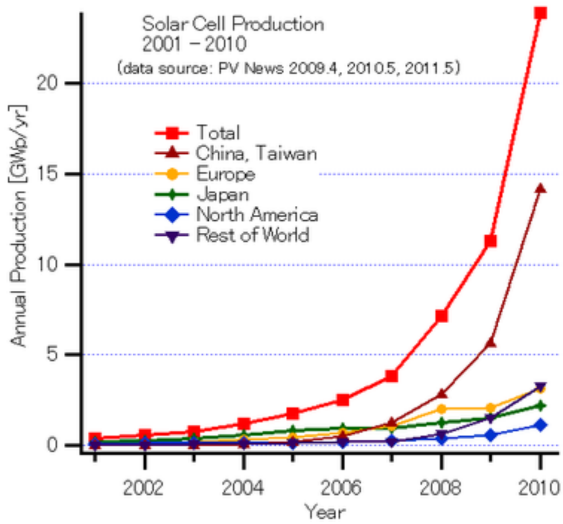


Figure 1-2. World solar cell production 2001-2010

Source: (Wikipedia, 2019)

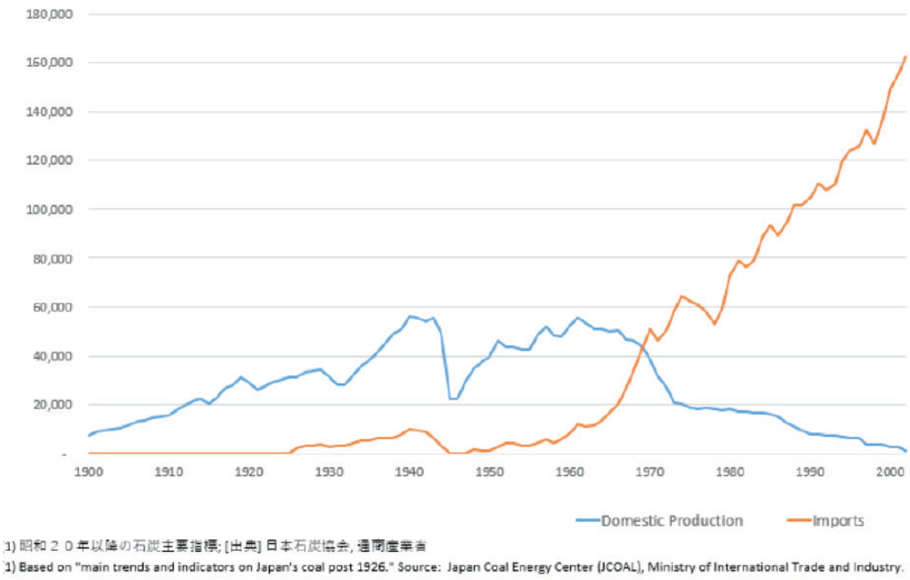


Figure 1-3. Coal production and import (1000 Metric Tons) – Japan 1900-2002

Source: METI

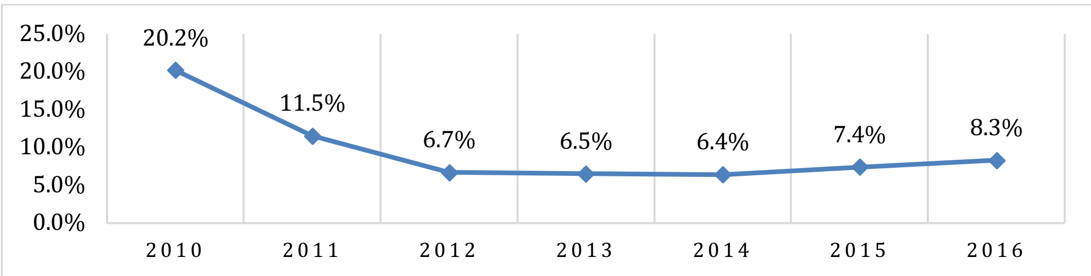


Figure 1-4. Energy self-sufficient ratio - Japan

Source: (MITI, 2017)

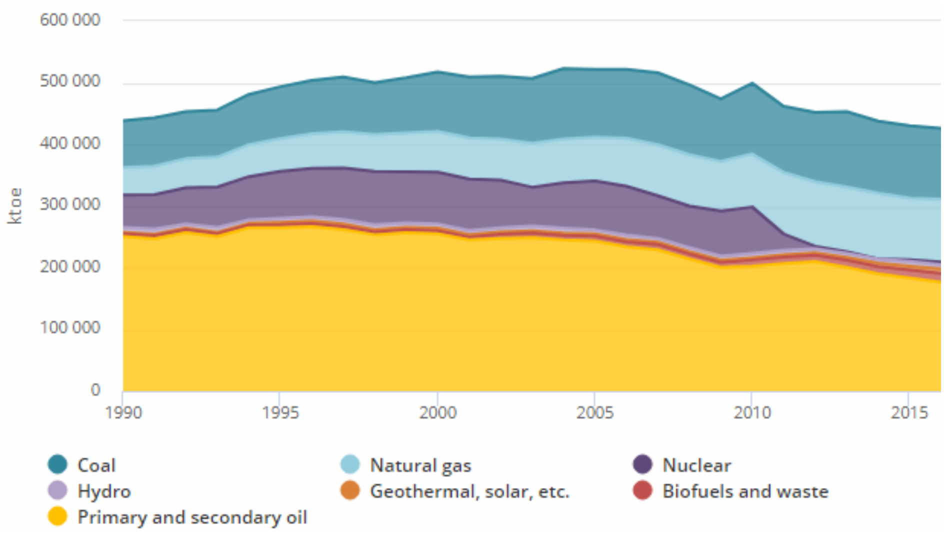


Figure 1-5. Total primary energy supply by source – Japan

Source: (IEA, 2019)

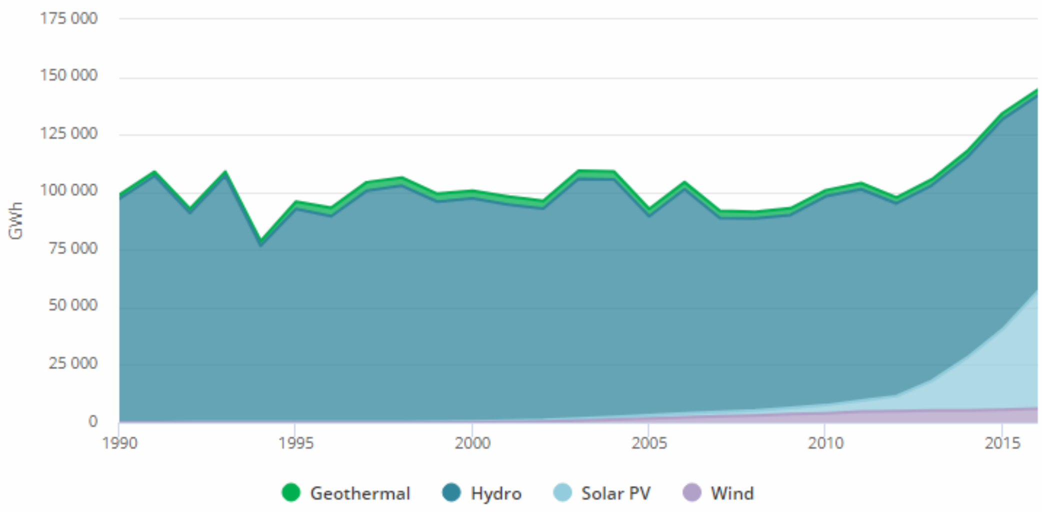


Figure 1-6 Electricity generation from renewable sources – Japan

Source: (IEA, 2019)

1.3 Germany Renewable Energy

Germany is one of the countries with the least irradiation of sunlight in the world but is the fourth leading producer of solar photovoltaic power in the world with 45.4 GW installed capacity (FraunhoferISE, 2019). As seen in *Figure 1-7*, for decades, coal and natural gas have played a key role in the total primary energy supply. Renewable energy introduction was seen as means to reduce emission of greenhouse gases (*Figure 1-11*) as well as costs of importation of coal, which gave rise to the electricity generated from renewables (Figure 1-8, 15). In 2017, the share of total energy produced in Germany reached a 33.3% dominated by hydro, biomass and solar photovoltaics (*Figure 1-9*). Also, the total number of solar PV systems installed reached 1.6 million producing nearly 43 GW (BMWi, 2018).

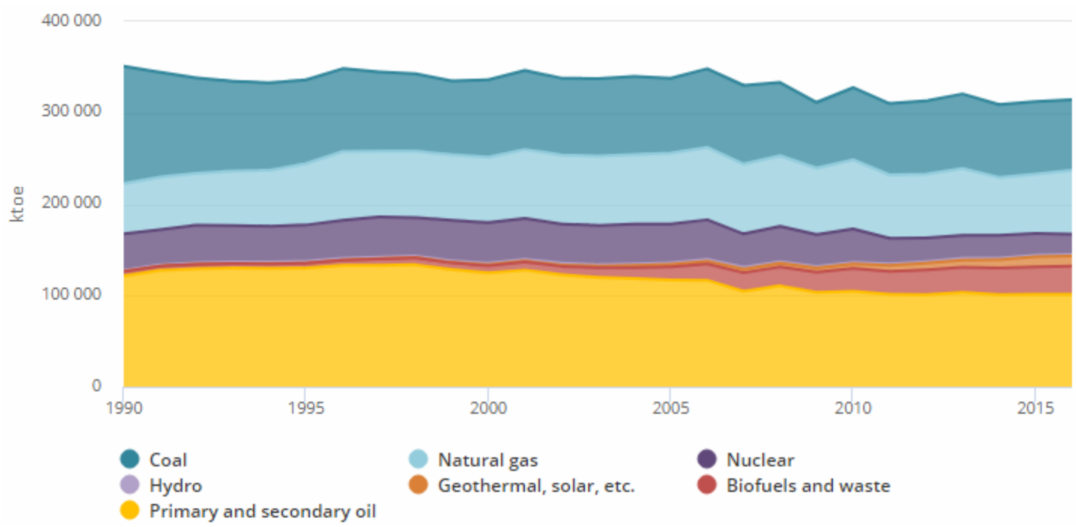


Figure 1-7. Total primary energy supply by source – Germany

Source: (IEA, 2019)

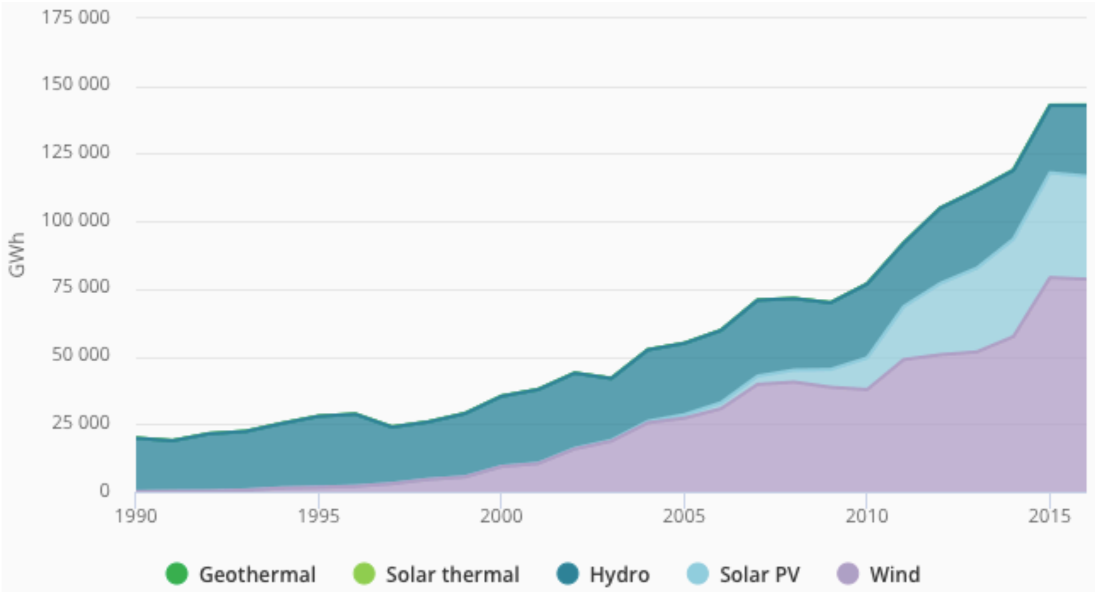


Figure 1-8. Electricity generation from renewable sources - Germany

Source: (IEA, 2019)

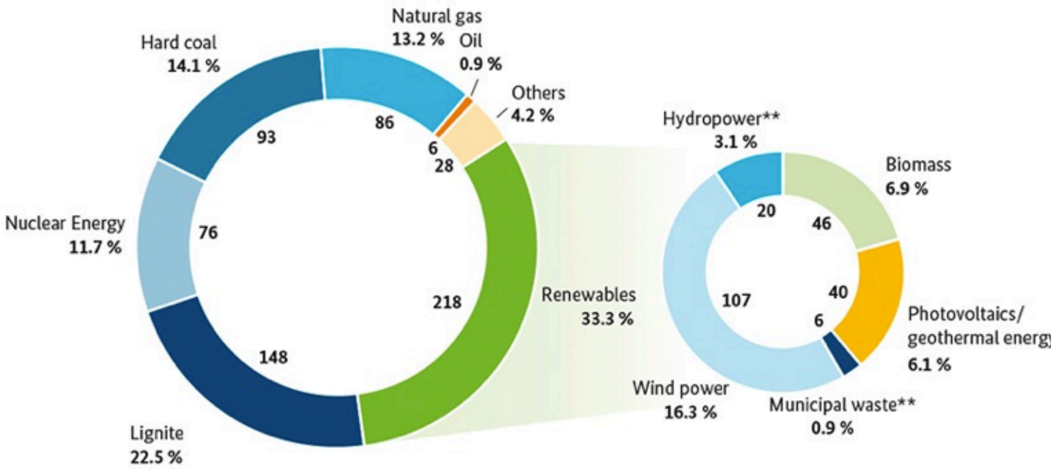


Figure 1-9. Energy mix in 2017 - Germany

Source: (BMWi, 2018)

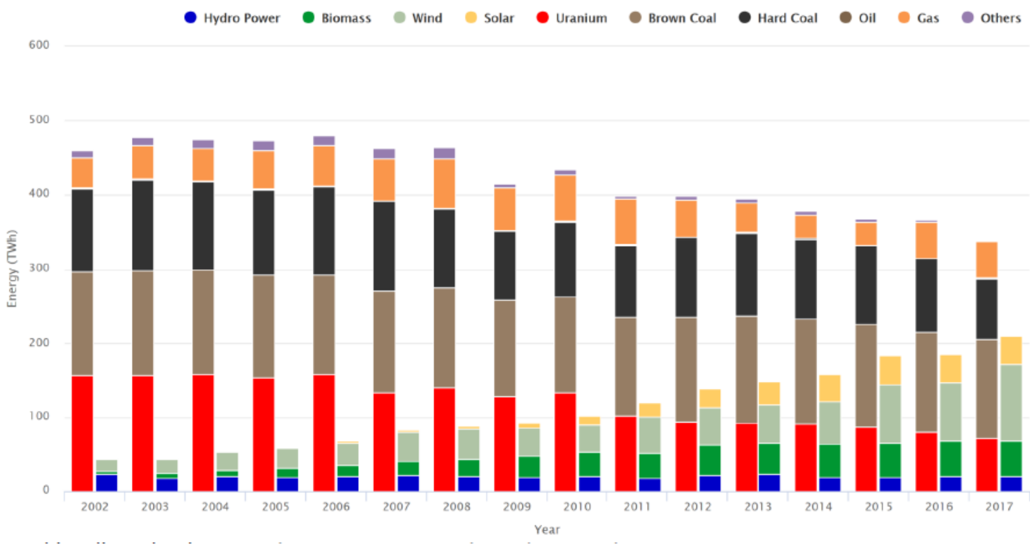


Figure 1-10. Trends in power generation from conventional and renewable sources – Germany

Source: (FraunhoferISE, 2019)

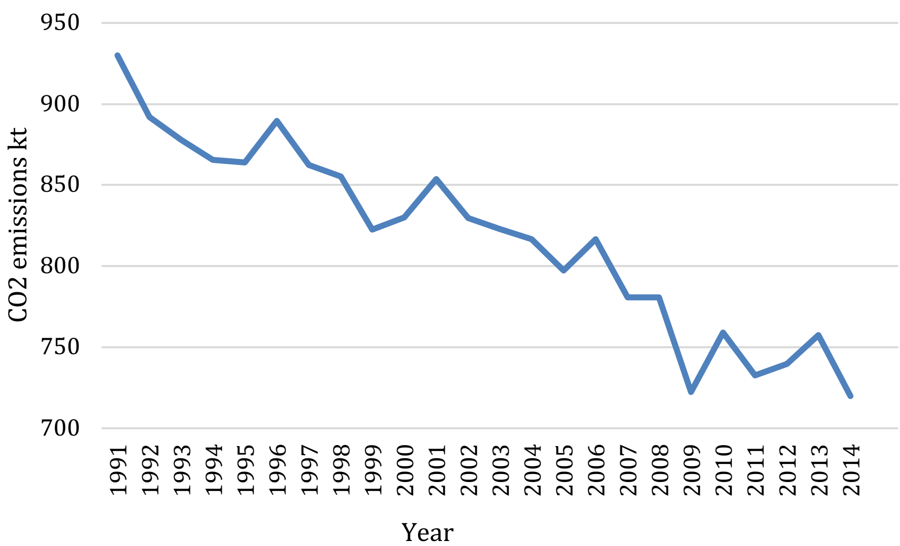


Figure 1-11. Greenhouse gas emissions in Germany 1991-2014

Source: (METI, 2016)

1.4 Research Objectives & Questions

Innovative performance of a country have identified by many scholars as one of the drivers of economic development (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). However, most researches have looked in an overall context by examining how policies for example drives innovative performance of a country in broader terms. Hence the need for a systemic analysis of an innovation system of a country. Technological systems have an impact on the creation, diffusion and use of innovations in a country (Carlsson & Stankiewicz, 1991) but why some countries have a more advanced and developed PV technological systems than others? Hence the need to research on the evolution of technological systems and compare. Main focus of this research is understanding in a systemic perspective the evolution of advanced technological innovation systems for solar Photovoltaics of Japan and Germany as well as that of Tanzania which is still at its early stages of development. To accomplish this research objectives the following research questions will be addressed.

1. What are the determinants of solar PV technology diffusion and success in Japan and Germany
2. Which diffusion model explains the trajectories in Japan and Germany
3. What set of policies including public and technological are necessary for Tanzania to develop solar PV adoption

1.5 Significance of the Research

According to World Bank (2017) Tanzania is at a 32% electrification rate which is way behind the electrification plan set out in 2008 by the Power System Master Plan, 60% by 2020 and 90% by 2035 (JICA, 2017). Tanzania through the Big Result Now (BRN) strategic plan had identified key areas for strategy development with energy being one of them in order to transform Tanzania into a middle-income economy by 2025. The findings of this research will give insights to key decision makers on possible issues that may contribute to fall-out of the system and help Tanzania accelerate its electrifications by drawing lessons from Japan and Germany.

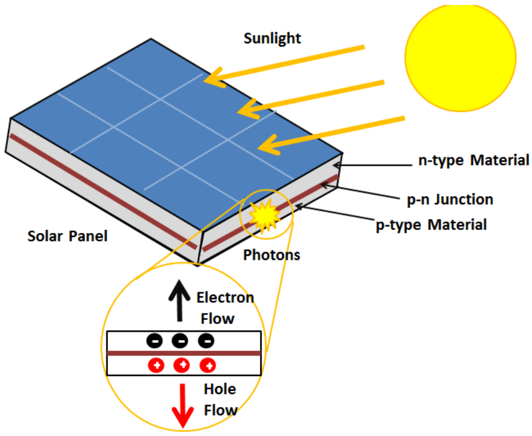
1.6 Scope and Limitation of the Research

This research will attempt to study the evolution of solar PV technology in Tanzania, Japan and Germany by holistically looking into the dynamics of their technological innovation systems (TIS) for solar PV. The dynamics will involve assessing the key actors and major interactions in the system. The research will also attempt to look into the major historical events occurred from the first engagement of solar related activities in the country. Analyzing the TIS in a systemic way will be vital in understanding the building blocks of each system which in turn will help measuring its performance as well as identifying major differences between the three systems. The data for this research covered all the sub-markets of solar PV industry in an overall basis rather than separately for comparison terms. Also the data related for Tanzania solar installed capacities were missing making the forecasting difficult.

2 LITERATURE REVIEW

2.1 Solar PV technology

Solar energy is the electricity obtained directly from the conversion of sunlight into electricity (Green, 2000). The generated electricity directly from the sun is free, environmental friendly, mitigate greenhouse gases emissions, low cost of maintenance and operation as compared to other conversional sources of energy. The photovoltaic effect, and a solar cell operating principle was first discovered by the French physicist Edmond Becquerel in 1939 (Hosenuzzaman, et al., 2014). Silicon, the second most abundant semiconducting material is commonly used in the creation of a solar cell which is composed of two different types of semiconductors called P-type and N-type combined to make a P-N junction. At the P-N junction electric field is formed because electrons move towards the P-side and holes move towards the N-side. In the P-N junction, when sunlight which contains photons falls into a solar cell, the energy in the photons turns into an atom causing the electrons to jump into a higher energy state leaving a hole in a valence band (Boyle, 2004). When unexcited, electrons hold the semiconducting material together by forming bonds with surrounding atoms, and thus they cannot move. However in their excited state in the conduction band, these electrons are free to move through the material. Because of the electric field that exists as a result of the p-n junction, electrons and holes move in the opposite direction as expected. Instead of being attracted to the p-side, the freed electron tends to move to the n-side. This motion of the electron creates an electric current in the cell. Once the electron moves, there's a "hole" that is left. This hole can also move, but in the opposite direction to the p-side. It is this process which creates a current in the cell.



Created internally by a member of the Energy Education team. Adapted from: Ecogreen Electrical. (August 14, 2015). Solar PV Systems *[Online]. Available:* http://www.ecogreenelectrical.com/solar.htm

Multiple PV cells include a PV module and multiple PV modules are connected in series or in parallel in a PV array system. The applications for solar cells depend on characteristics of individual cells in addition to the environmental conditions. Solar photovoltaics are used in a variety of applications such as spacecraft, water pumping, Lighting Street, Building Integrated Photovoltaic Systems (BIPV), telecommunications, water desalination, satellites and weather monitoring (Sampaio & González., 2017).

2.2 Diffusion of Innovations

In recent years there has been an increase in using electricity generated from solar panels around the world. Since its invention, Solar panels have become part of life of many societies in the world. Solar electricity is a phenomenon innovation that people didn't know it six decades ago. When an idea is spread into a population from a single or multiple sources is called diffusion. The spread of an innovation (something new) in the population is termed as diffusion which was defined as the process by which an *innovation* (idea, technology or product) is communicated through certain *channels* over *time* among the members of a defined *social system* (Rogers, 2003).

> *"Innovation diffusion is the process of the market penetration of new products and services, which is driven by social influences. Such influences include all of the interdependencies among consumers that affect various market players with or without their explicit knowledge"* (Peres, Muller, & Mahajan, 2010)

According to Everett M. Rogers (2003), diffusion has main four elements

1. Innovation: an idea (solar electricity generation), practice, or object (solar panels) that is perceived as new by an individual or other unit of adoption. An innovation has five attributes: relative advantage, compatibility, complexity, trialability and observability.
2. Communication channels: the means by which messages get from one individual to another. Mass media channels and interpersonal channels are useful in creating knowledge of innovations as well as influencing the decision of whether to adopt or reject an innovation.
3. Time
4. Social system: set of interrelated units that are engaged in joint problem solving to accomplish a common goal.

Technologies do not spread instantaneously (Rogers, 2003). Instead, the diffusion process which involves adopting and applying the new technology takes time to spread along the social system (Perkins & Neumayer, 2005).

Global adoption or substitution of an innovation is comprised of two stages; the time an innovation became available in the world and when it first appeared in the country i.e. implementation stage (Dekimpe, Parker, & Sarvary, 2000). A key issue discussed in some literatures concerning diffusion of innovations is the order of entry. The *entry time lag* has a positive influence on the diffusion process (Kesidou, 2004). It is predicted that a new technology will be adopted in developed economies first while the countries that introduce a given technology later will exhibit a faster diffusion process (Dekimpe, Parker, & Sarvary, 2000) and a shorter time to takeoff (Tellis, Stefan, & Edin, 2003). This because developed economies due to the financial prowess are in a good position to be profitable with the technology than the least developed countries. Also Developed countries due to their financial power are better suited to absorb any losses arising from the adoption of an innovation (Rogers, 2003).

Perkins & Neumayer (2005) pointed out that: developing economies which have small capital stock and late-adoption will diffuse a new technology faster than the counterpart developed countries. But due to the *late-comer advantage* concept argued by many researchers, developing economies late-industrialization status they are more suited to diffuse a new technology more rapidly (Perkins & Neumayer, 2005). This is due to the fact that, countries that adapt a technology later will benefit from developments realized by the initial developers. Kesidou, (2004) mentioned issues like foreign direct investments, imports and licencing to be the facilitators of adaptation to new technologies. Asian countries like Malaysia, South Korea and Japan have seen their rapid growth facilitated by the initial copying of technologies that were originally developed in industrialized economies (Sung & Carlsson, 2003) .

Recent empirical studies suggest geographical location also plays a vital role in the diffusion of a technology (Keller, 2001). When an innovation is already available in a neighbor countries, the chances are higher that it will also diffuse in another countries due to what Kim & Nelson, (2000) called a “geographical proximity”

2.3 Models of technological innovation diffusion

Diffusion models attempt to analyze the process by which an innovation is diffused throughout a determined social system (Rogers, 2003). Diffusion model try to predict how the product or an innovation will grow in the population from the first adoption until all members in the population have adopted.

Rogers, (2003) pointed out that, when the cumulative adoption time path of a diffusion process is plotted, the resulting distribution can be described as taking the form of an S-shaped curve as seen in (*Figure 4-19*). Initially only few members of the social network adopt the innovation due to interpersonal communications and words of mouth the number rapidly increases. It reaches a point where the trajectory of the diffusion curve slows down reaching a saturation point. Most innovations have different diffusion patterns for example, the slope may be steep indicating rapid diffusion or gradual indicating a slow diffusion.

In the designing a diffusion of an innovation model that is accurate, reflects real events it represent and consider all parameters is a difficult task for developers also requires users to understand the general assumptions underlying model formulation. For this reason there are simplifying-assumptions that were put in place to smoothen the analytical solutions of such models. First, researchers in the field of diffusion of innovation pointed out that the diffusion process of an innovation is treated as a *discrete* as well as *binary* (Sharif & Ramanathan, 1981). For the diffusion process to be discrete rather continuous means that models do not consider stages in the diffusion process.

Second, the fundamental diffusion model assumes that the carrying capacity$\overline{N}$, which is the total number of potential adopters in the social system, is distinct and constant and it can either be calculated or estimated. This phenomenon makes the fundamental diffusion model being *static* i.e. the size of the social system will always remain constant during the course of a diffusion process (Mahajan & Peterson, 1985).

Third, during the course of a diffusion process only one-adoption of an innovation i.e. single purchase is allowed in the fundamental diffusion model. Also, simultaneously the fundamental diffusion model does not take into an account the fact that after first purchase at some point the adopter may discard the innovation.

The fourth assumption is that the innovation is considered to not changing over time during the diffusion process. So, if improvements are made to an innovation the changes will never count in the fundamental diffusion model. A good example of this scenario is, if a technological innovation has some modifications done to its original form it will be deemed as independent.

To apply and interpret the results of any diffusion model it better to understand it's conceptual as well as mathematical foundation which is the differential equation expressed as follows

$$\frac{dN(t)}{d(t)} = g(t)[m - N(t)], N_{t=t_0} = N_0 \qquad \text{Eq. (1)}$$

Where

m= total number of potential adopters in the social system at time t,[5]

$N(t)$ = cumulative number of adopters at time t

$$N(t) = \int_{t_0}^{t} n(t)dt,$$

$n(t)$ = Non-cumulative number of adopters at time t,

[5] The $\overline{N}$ can be regarded as the carrying capacity of the social system who are the potential adopters i.e. asymptote of the diffusion curve

$\frac{dN(t)}{d(t)}$ = rate of diffusion at time t,

$g(t)$= coefficient of diffusion[6]

N_0 = cumulative number of adopters at time t_0.

The diffusion model presented in equation 1 suggests that's the rate of diffusion of an innovation at time t is the function of the difference between total number of possible adopters existing at that time and the number of previous adopters at time t, $[\overline{N} - N(t)]$. It can be observed from this model formulation that, when $N(t)$ is approaching $\overline{N}$ the rate of diffusion will be decreasing and vice versa.

Interpreting the function $g(t)$, which can be interpreted as the probability that an innovation will be adopted at time t, represent the nature of relationship between the diffusion rate, $\frac{dN(t)}{d(t)}$ and number of potential adopters at time t, $[m - N(t)]$. Having this interpretation it means that, the function $g(t) * [m - N(t)]$ represent the potential number of adopters at time t, $n(t)$. If $n(t)$ is seen as number of social system members transformed from potential-adopters to adopters of an innovation then the function $g(t)$ will also be a transfer mechanism. In concluding, $g(t)$ will then be represented as the function of time or number of previous adopters. Further analyzing $g(t)$ as the function of number of adopters $N(t)$ as mentioned earlier, the equation will be as follows

$$g(t) = p + qN(t) + cN(t)^2 + \ldots$$

For the simplicity of parameter estimations later, $g(t)$ can be further presented as either

$g(t) = p$,

$g(t) = qN(t)$, or

[6] As discussed in the literature, the specific values of the function $g(t)$, will depend on the characteristics of diffusion process such as nature of innovation itself, communication channels, and the attributes of the social system (Mahajan & Peterson, 1985).

$g(t) = (p + mN(t))$,

Where a, and b are model coefficients or parameters. When placing values of $g(t)$ to the above equations, we will have three different types of diffusion models.

First, If $g(t) = a$, the fundamental diffusion model can be expressed as

$$\frac{dN(t)}{d(t)} = p[m - N(t)] \qquad \text{Eq. (2)}$$

Most scholars refers this equation as the *external-influence* diffusion model.

From the equation (2), the term "a" represent the coefficient of external influence coming from outside the social system such as mass-media, government push, and sales people. The critic about this model is it does not consider the interaction between prior adopters and potential adopters because diffusion is considered to be driven by the information outside of the social system. This model was popularized by the work of Fourt and Woodlock (1960) when they forecasted the sales of grocery products. As seen from the *Figure 2-1* where the saturation level is 40%, the curve doesn't have a point of inflection because as time goes the cumulative number of adopters rises at a constant diminishing rate.

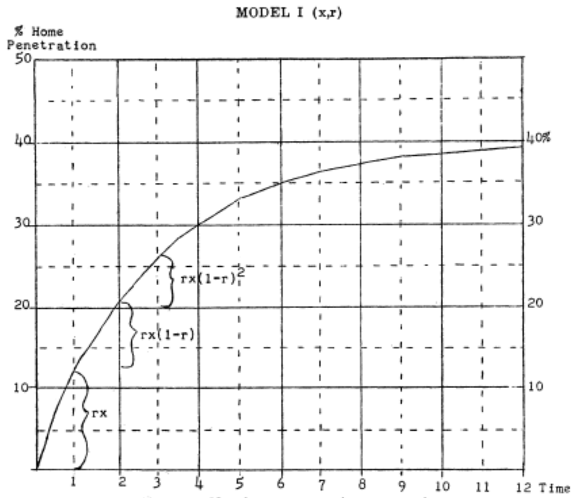


Figure 2-1. Forecasted sales curve

Source: (Fourt & Woodlock, 1960)

Second, If $g(t) = bN(t)$, the fundamental diffusion model can be expressed as

$$\frac{dN(t)}{d(t)} = qN(t))\ [m - N(t)] \qquad \text{Eq. (3)}$$

This equation will referred to as the *internal-influence* diffusion model. A famous model relating to this, which will be used as a methodology in this research is Gompertz model.

Third, If$g(t) = (a + bN(t))$, the fundamental diffusion model can be expressed as

$$\frac{dN(t)}{d(t)} = (p + qN(t))\ [m - N(t)] \qquad \text{Eq. (4)}$$

This equation will referred to as the *mixed-influence* diffusion model since it incorporates the external and internal influences in a single model. The famous Bass model is relating to this, as he applied the mixed-influence concept in his model successfully predicting the sales of different products such as TVs, and clothes (Mahajan & Peterson, 1985). Bass model will be used as a methodology in this research.

Despite the fundamental diffusion model and the associated modifications i.e. internal-influence, external-influence and mixed-influence being applied extensively in various applications for forecasting but they have also received some criticism (e.g. absence of flexibility, assumptions made). Reevaluating the basic structure of fundamental diffusion model, two mathematical properties *point of inflection*[7] and *symmetry*[8] are employed. Practically, in any innovation the point of inflection should be able to appear at any point in the diffusion curve as well as being symmetric or non-symmetric. However, both the internal-influence and mixed-influence models offer a limited

[7] Point of inflection on the diffusion curve occurs when the maximum rate of diffusion is reached.
[8] Symmetry occurs when the diffusion pattern after the point of inflection is the mirror image of diffusion pattern before the point of inflection.

flexibility as far as these two properties are concerned (Mahajan & Peterson, 1985). This lack of flexibility may be the reason why these models fit in some applications but not the others. To respond to the earlier mentioned deficiencies, scholars in the field of diffusion of innovation have presented flexible diffusion models (*Figure 2-2*). In this research two flexible diffusion models, Sharif – Kabir and Floyd will be applied.

Model	Model Equation (dF/dt =)	Model Solution (F =)	Point of Inflection (F*)	Symmetry[a]	Coefficient of Internal Influence	Illustrated Reported Applications
1. Bass (1969)[b]	$(p + qF)(1 - F)$	$\frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}$	.0–.5	NS	Constant	Consumer durable goods; retail service, agricultural, education, and industrial innovations; electronics, photographic products, industrial processes
2. Gompertz curve[c] (see Hendry 1972; Dixon 1980)	$qF \ln\left(\frac{1}{F}\right)$	$e^{-e^{-(c+qt)}}$	.37	NS	Constant	Consumer durable goods, agricultural innovations
3. Mansfield (1961)	$qF(1 - F)$	$\frac{1}{1 + e^{-(c+qt)}}$	.5	S	Constant	Industrial, high technology, and administrative innovations
4. Floyd (1962)	$qF(1 - F)^2$	*	.33	NS	Decreasing to zero	Industrial innovations
5. Sharif and Kabir (1976)[d]	$\frac{qF(1 - F)^2}{1 - F(1 - \sigma)}$	*	.33–.5	S or NS	Constant or decreasing to zero	Industrial innovations
6. Jeuland (1981)[e]	$(p + qF)(1 - F)^{1+\gamma}$	*	.0–.5	S or NS	Constant or decreasing to zero	Consumer durable goods
7. Nonuniform influence (NUI) (Easingwood, Mahajan, and Muller 1983)	$(p + qF^{\delta})(1 - F)$	*	.0–1.0	S or NS	Increasing, decreasing, or constant	Consumer durable, retail service, and education innovations
Nonsymmetric responding logistic (NSRL, p = 0 in NUI) (Easingwood, Mahajan, and Muller 1981)	$qF^{\delta}(1 - F)$	*	.0–1.0	S or NS	Increasing, decreasing, or constant	Medical innovations
8. Nelder[f,g] (1962; see McGowan 1986)	$qF(1 - F^{\phi})$	$\frac{1}{[1 + \phi e^{-(c+qt)}]^{1/\phi}}$	.0–1.0	S or NS	Decreasing to a constant	Agricultural innovations
Von Bertalanffy[h] (1957; see Richards 1959)	$\frac{q}{1 - \theta} F^{\theta}(1 - F^{1-\theta})$	$[1 - e^{-(c+qt)}]^{1/1-\theta}$	.0–1.0	S or NS	Decreasing to a constant	
9. Stanford Research[i] Institute (e.g., Teotia and Raju 1986)	$\frac{q}{t} F(1 - F)$	$\frac{1}{1 + \left(\frac{T^*}{t}\right)^q}$	.0–.5	NS	Decreasing to zero	Energy-efficient innovations
10. Flexible logistic[j] growth (FLOG; (Bewley and Fiebig 1988)	$q[(1 + kt)^{1/k}]^{\mu-k}$	$\frac{1}{1 + e^{-[c+qt(\mu,k)]}}$	.0–1.0	S or NS	Increasing, decreasing, or constant	Telecommunication innovations

Figure 2-2. Flexible Diffusion Models

Source: (Mahajan, Muller, & Bass., 1990)

2.4 Tanzania Renewable Energy

Tanzania is rich in primary energy resources (hydro, wind, coal, geothermal, solar[9], and natural gas[10]) with most being unexploited. About 90% of the total primary energy supply is supplied from biomass, about 8% petroleum and only 0.5% supplied by coal-fueled power plants and other renewable energies (*Figure 2-3*). Greater percentage of more than 75% of energy supplied by biomass is used in rural area which constitute 67% of 57 million population (WorldBank, Tanzania, 2017) which resulting into deforestation (Sheya & Mushi, 2000). To date, about 32% of the country's population has access to basic electricity leaving huge population (64%) uncovered by the national electricity grid (*Figure 2-3*).

The supply of electricity in Tanzania is both through interconnected systems and isolated systems (EWURA, 2017) with TANESCO being the only supplier in Tanzania mainland, the excess electricity is supplied to Zanzibar[11]. To improve its supply capacity, TANESCO buys electricity from IPPs[12] as well as imports from Zambia (5 MW) and Uganda (8 MW). *Figure 2-4* shows the major actors involved in the generation, distribution and supply of electricity in Tanzania. Tanzania enjoys a 7.1% annual growth rate (WorldBank, 2017). The growth rate comes with an increase in demand and consumption of electricity in major economic sectors (*Figure 2-5*). Same as instituted by Japan and Germany, after the oil shock in 1973 Tanzania started to consider implementing renewable energies such as solar PV as a mean to power off-grid areas (Sheya & Mushi, 2000). The impetus of creating markets for solar PV

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[9] Solar irradiation of about 3500 sunshine hours per year, at an average of 7 kWh/m2/day (SolarGIS, 2019).

[10] The natural gas discoveries are 47.83 trillion cubic feet.

[11] A semi-autonomous island region of Tanzania composed of two large islands Unguja and Pemba

[12] TANESCO produces about 53% of total power, and the three IPPs 46% (Author's compilation)

systems was through the initial demand of schools and health institutions for solar systems (GIZ, 2009).

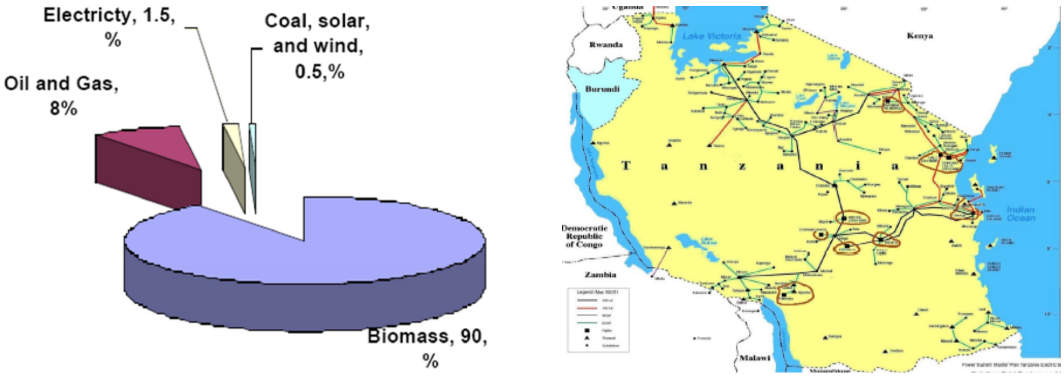


Figure 2-3. Total primary energy supply by source (left), main electricity grid (right) – Tanzania

Source: (JICA, 2017)

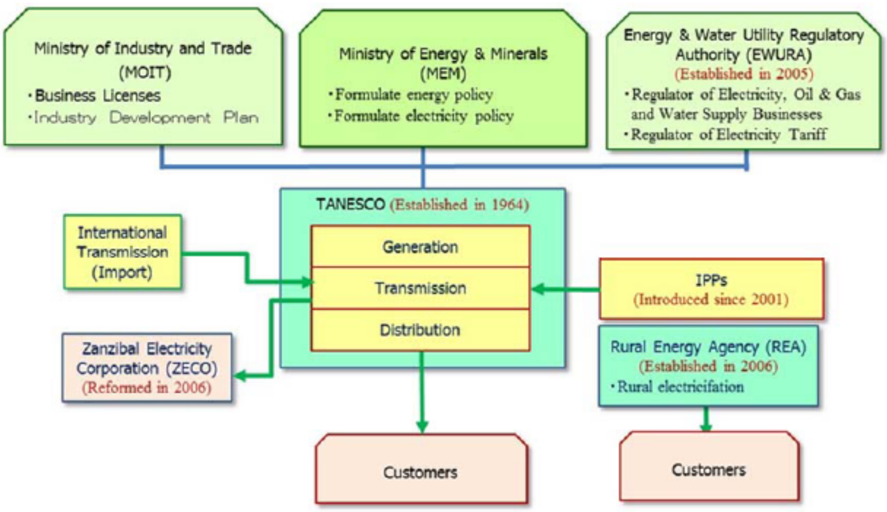


Figure 2-4. Major actors in electricity generation, distribution and supply – Tanzania

Source: (TANESCO, 2007)

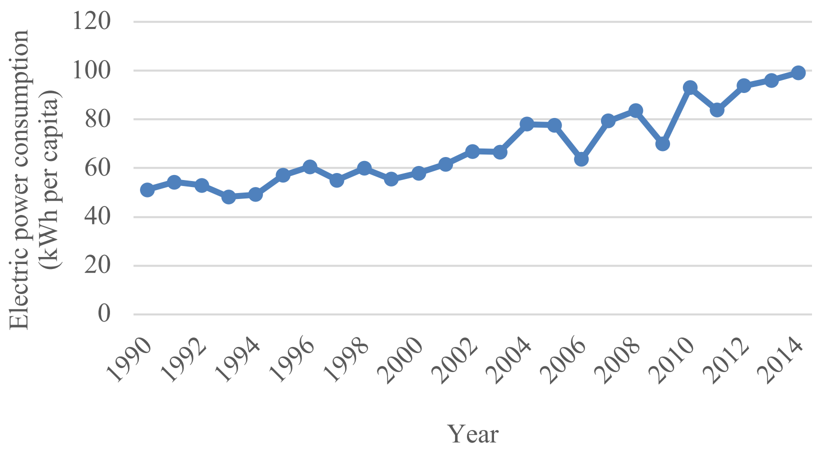


Figure 2-5. Electric power consumption - Tanzania

Source: (WorldBank, 2019)

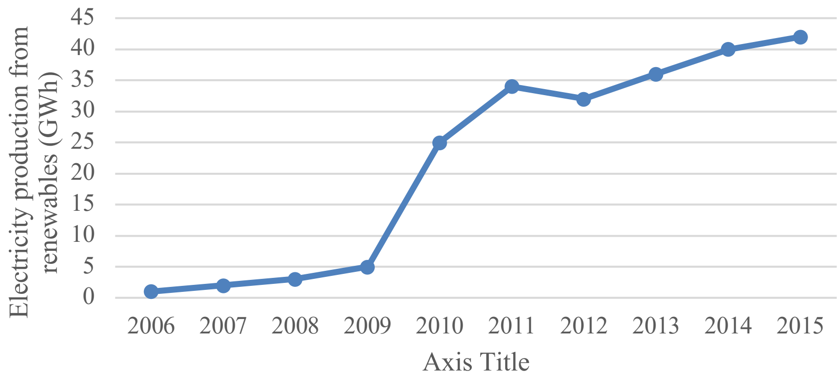


Figure 2-6. Electricity production from renewables - Tanzania

Source: (WorldBank, 2019)

3 RESEARCH METHODS

In this section we presented the methods that were used to address the research questions. Tanzania was selected due to prior understanding of the actors involved in the solar PV industry, while Japan and Germany was selected for the easy of getting data as well the fact that they are leading countries in solar PV industry with interesting growth trajectories for learning purposes.

3.1 The Data

This research is based on the installed solar PV capacity datasets published by the IEA National Survey Reports of PV Power Applications in Japan (*Figure 3-1*) and Germany (*Figure 3-2*) ranging from 1990 to 2017.

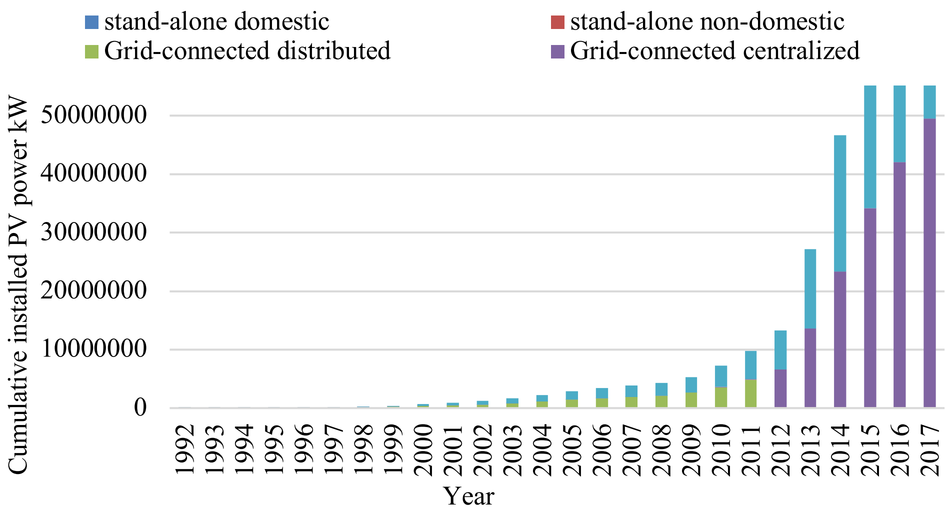


Figure 3-1. The cumulative installed PV power in 4 sub-markets – Japan

Source: (IEA-PVPS, 2019)

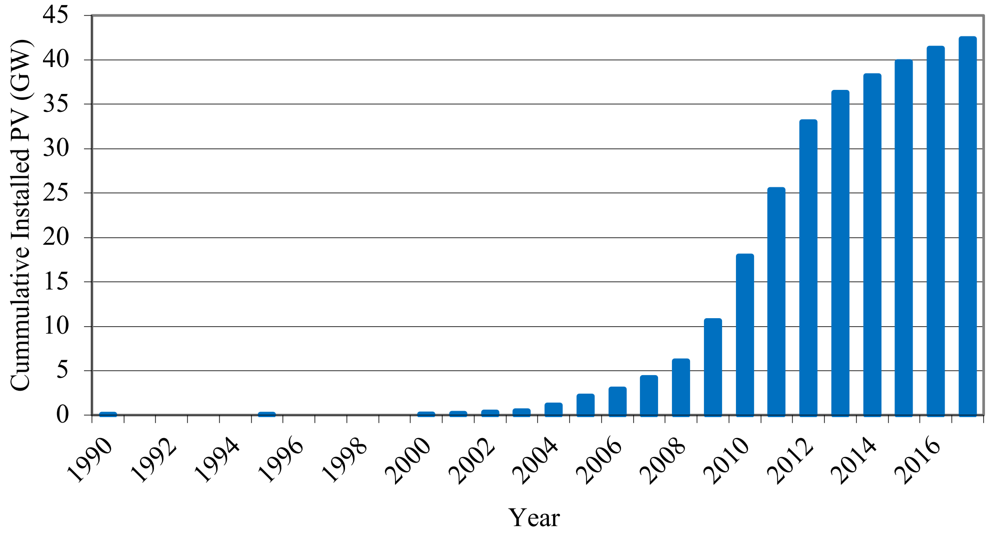


Figure 3-2. The cumulative installed Solar PV power – Germany

Source: (IEA-PVPS, 2019)

For understanding the technological innovation systems of Tanzania, Japan and Germany in a systemic way, the events[13] occurred that are related to the components of TIS for solar PV diffusion were captured from academic journal articles, websites, reports, and interviewing experts.

3.2 The Models

3.2.1 Internal Influence Model [Gompertz]

From the earlier elaboration that external-influence model is based on the premises that there is no interpersonal communications i.e. only external communications drives diffusion process, in the internal-influence model diffusion process occurs through *interpersonal communications* within the social system. This means that, the rate of

[13] We couldn't mention all events occurred, but the most important events to explain diffusion of solar PV were included.

diffusion is the function of interpersonal interactions between prior adopters and potential adopters within the social system i.e. [prior adopters] x [potential adopters]. From the equation (3), $\frac{dN(t)}{d(t)} = bN(t))\left[\overline{N} - N(t)\right]$the term "b" represents index of imitation or the internal influence when prior adopters and potential adopters interacts. As seen in *Figure 3-3* when the cumulative number of adopters is plotted against time, the outcome is the S-curve having the inflection point when the total number of potential adopters reaches 50% of the carrying capacity.

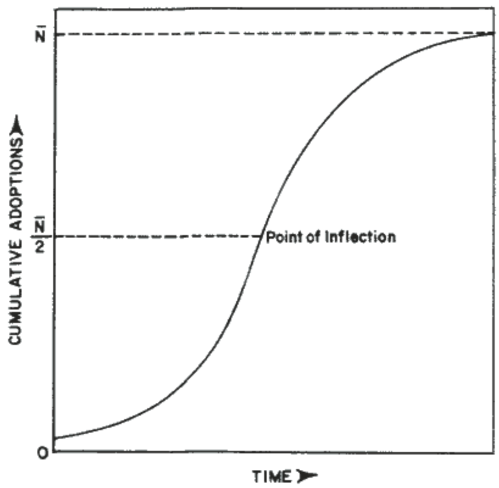


Figure 3-3. S-Curve with the 50% point of inflection

Source: (Mahajan & Peterson, 1985)

In the field of technological forecasting, Gompertz model is the famous model directly related to internal influence model. From the original internal influence (equation 3), the Gompertz function can be expressed as

$$\frac{dN(t)}{d(t)} = bN(t))\left[ln\overline{N} - lnN(t)\right] \qquad \text{Eq. (5)}$$

or

$$y(t) = ae^{be^{ct}} \quad \text{Eq. (6)}$$

$$\frac{dN(t)}{d(t)} = \overline{N} * e^{-a*e^{-bt}} \quad \text{Eq. (7)}$$

Where all the variables and parameters have their previous meanings, the $\overline{N}$, a, and b are all positive. The Gompertz function ranges from a lower asymptote of 0 to the upper bound $\overline{N}$ as time ranges from -∝ to +∝. As seen in the *Figure 3-4*, the first derivative solution of the equation (7) results into a $0.37\overline{N}$ point of inflection. Hence, the maximum growth rate $\frac{\overline{N}*b}{e}$ is achieved when diffusion reaches around 37% of the saturation level.

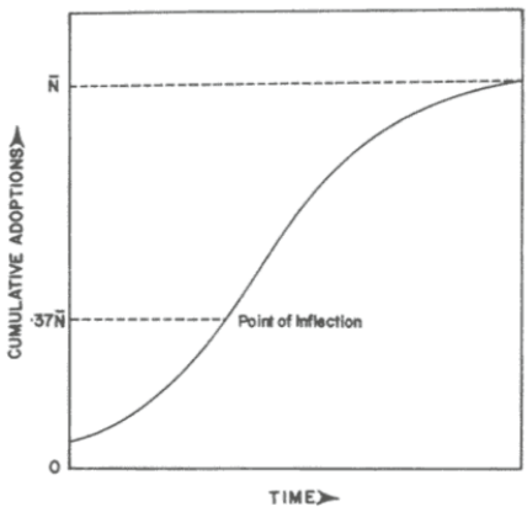


Figure 3-4. S-Curve for Gompertz curve

Source: (Mahajan & Peterson, 1985)

3.2.2 Mixed Influence Model [Bass Model]

As elaborated earlier in literature review, the *mixed-influence* diffusion model incorporates the external and internal influences in a single model. The model equation is:

$$\frac{dN(t)}{d(t)} = (a + bN(t))\left[\overline{N} - N(t)\right]$$

The fact that the mixed-influence model incorporates both external and internal influences, it is arguably the most widely used model amongst the three fundamental models. Mostly popularized by Bass (1969), the mixed-influence model has widely being applied to the forecasting of consumer long-lasting products' sales. Mahajan and Muller (1979) modified and applied the mixed-influence model in the context of new product growth forecasting in marketing. Warren (1980) also modified the model to explore and forecast the market potential of a new solar technology.

Traditionally, the main thread of diffusion models has been based on the framework developed by Bass (1969), a differential equation derived from a hazard function states that:

> *"The probability that an individual will adopt the innovation given that the individual has not yet adopted it is linear with respect to the number of previous adopters"* (Bass, 1969).

The Bass model suggested that, the probability that someone would adopt an innovation given that there isn't a prior adoption is represented by the following basic equation underlying the bass model.

$$\frac{n(t)}{(1 - N(t)} = p + qN(t)$$ Eq. (8)

Where,

$n(t)$ = Density function of adoption at time t,

$N(t)$ = Cumulative fraction of adopters at time t,

p = Coefficient of innovation (external influence),

q = Coefficient of imitation (interpersonal influence).

Differentiating the term $N(t)$ which is $n(t) = \frac{dN(t)}{dt}$, the equation (5) can also be written as

$$\frac{dN(t)}{d(t)} = p + (q - p)N(t) - qN(t)$$ Eq. (9)

Introducing the market potential term m into equation (9)[14], to give number of first time adopters of an innovation the equation (9) can also be expressed as

$$\frac{dN(t)}{d(t)} = p[m - N(t)] + \frac{q}{m}N(t)[m - N(t)]$$ Eq. (10)

From the equation (10), the adopters due to the external influence such as mass media will be represented by the term $p[m - N(t)]$ while the term $\frac{q}{m}N(t)[m - N(t)]$represents adopters of an innovation because of the interpersonal influence in a social system. The maximum diffusion rate time i.e. peak time can be calculated using the equation

$$t^* = (\frac{1}{(p + q)})ln\frac{q}{p}$$ Eq. (11)

[14] $n(t) = m[(1 - N(t) * (p + qN(t))]$

Also, the earlier equation (10) will be further simplified into the following equation

$$n(t) = \frac{dN(t)}{d(t)} = pm + (q - p)N(t) - \frac{q}{m}N^2(t) \qquad \text{Eq. (12)}$$

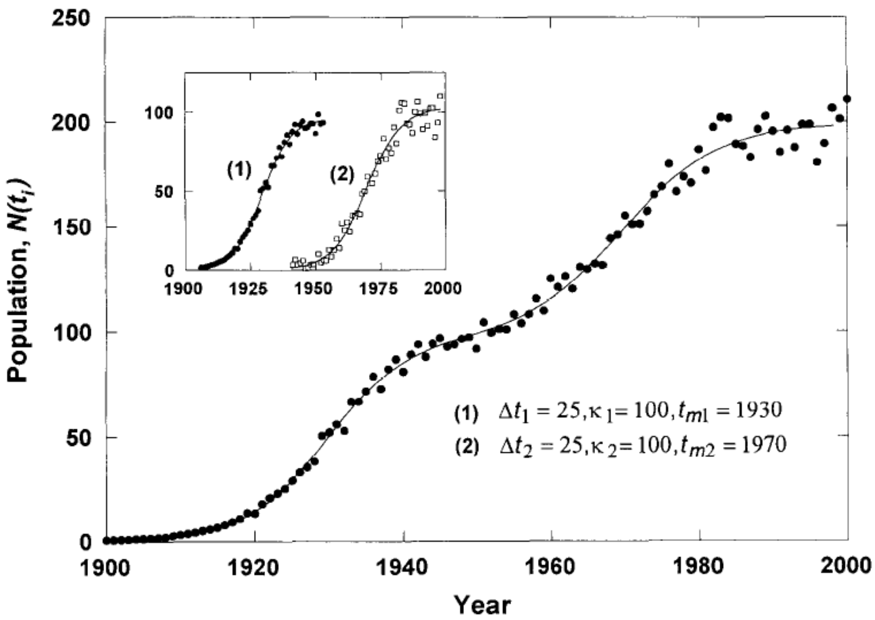
Since the terms p and q are coefficients of innovation and imitation respectively, the Bass model can show two basic shapes. Radas (2005) used the Bass model to plot the graphs using a market potential, $m = 1{,}500{,}000$ and varying values of p and q. When $q \geq p$ the shape of an S-curve will be a bell-shape. But when $q \leq p$ the shape will be downward slopping.

Despite its success in forecasting researches, Bass model has some drawbacks. Vijay Mahajan, Eitan Muller, Frank M. Bass (1990) pointed out the drawbacks to be:

1. In any diffusion curve, maximum rate of diffusion of an innovation do not occur after the innovation has been adopted by 50% of the potential adopters.
2. The diffusion curve is symmetric with respect to the inflection point

3.2.3 Bi-Logistic Model

As mentioned in the literature, most of life events such as biological, and social technical systems exhibit an S-shaped logistic growth model when their growth patterns are modeled. However, usually the carrying capacity in a social system is restricted to the existing level of technological advance, which is not static due to different forces such as technology transfer or new innovation influencing the change (Meyer, 1994). When the technology advances (carrying capacity changes) during the logistic growth, the growth pattern will have more than one phase whereby the second phase having a different carrying capacity will superimpose on the first phase. To model and analyze that phenomenon, Meyer (1994) presented the Bi-logistic[15] model by summing of two simple logistic growth phases.



Source: (Meyer, 1994)

Logistic growth assumes the population grows exponentially until the carrying capacity is approached where the growth rate slows down until it reaches the saturation point exhibiting an S-curve pattern. The growth rate of a population, $N(t)$ is proportional to the population.

$$\frac{dN(t)}{d(t)} = \propto N(t), t \rightarrow \infty, N(t) \rightarrow \infty \quad \text{Eq. (13)}$$

[15] Bi-logistic is useful in modeling many systems that contain complex growth processes not well modeled by the simple logistic.

Where, $\propto =$ the growth rate parameter.

The feedback term, $(1 - \frac{N(t)}{K})$ is added to the equation (21) to slow down the growth rate of the system as the carrying capacity, K is reached to give it an S-curved shape.

$$\frac{dN(t)}{d(t)} = \propto N(t)(1 - \frac{N(t)}{K}) \qquad \text{Eq. (14)}$$

The solution of equation (22), gives the logistic law of growth as presented below (Meyer, 1994):

$$N(t) = \frac{K}{1 + e^{-\propto t - \beta}} \qquad \text{Eq. (15)}$$

Where, t_m = the midpoint of the growth process.

To analyze systems exhibiting Bi-logistic growth, the model will be:

$$N(t) = \frac{K_1}{1 + e^{-\frac{\ln(81)}{\Delta t1}(t - t_{m1})}} + \frac{K_2}{1 + e^{-\frac{\ln(81)}{\Delta t2}(t - t_{m2})}} \qquad \text{Eq. (16)}$$

In estimating the parameters of Bi-logistic model, from the time-series datasets, the Non-Linear Least Square estimation (NLS) procedure can be used.

A number of curves can be produced from the Bi-logistic model, hence it is worthwhile to explain the taxonomy of Bi-logistic curves in order to theorize those patterns of an innovation diffusion. Meyer (1994), presented distinguishing four basic patterns (*Figure 3-5*) of Bi-logistic growth to be used as a reference when analyzing diffusion of innovation patterns.

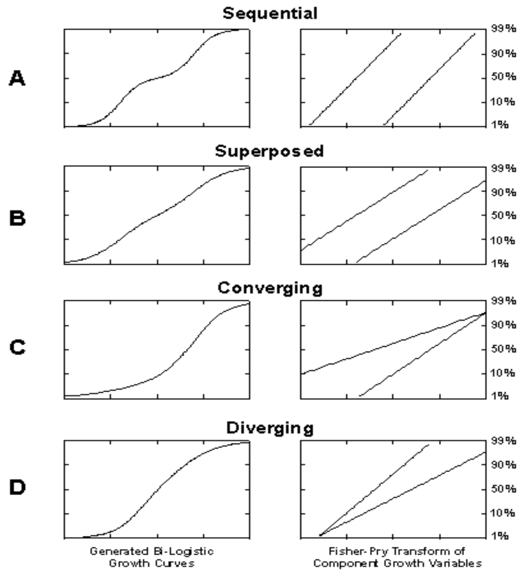


Figure 3-5.Taxonomy of Bi-logistic curves

Source: (Meyer, 1994)

From the Figure 3-5, pattern-A shows a sequential Bi-logistic curve with two nearly non-overlapping logistic growth phases. The second phase starts rising when the first phase reaches nearly 99% of saturation. This is an ideal case for a system that pauses between growth phases or the one that has reached a diminishing rate of return and is replaced by another phase (Meyer, 1994).

The pattern-B shows a superposed Bi-logistic curve where the second phase starts rising when the first phase had reached around 20-50% of saturation. This is an ideal case for a system that encompasses two processes of analogous behavior growing simultaneously except for a displacement in the midpoints of the curves. A good example is when scientific production leads to an improved science-based technologies (Schmoch, 2007)

The pattern-C shows a converging Bi-logistic curve where the faster second phase joins the first one to saturate at almost the same level. Usually the advance in technology will cause the second phase grows quicker causing the slope of the Fisher-Pry curve steeper.

The pattern-D shows a diverging Bi-logistic curve where the first and second phases both start at the same time but rising differently with different carrying capacities (Meyer, 1994).

3.3 Parameter Estimation Considerations

Applications of diffusion models requires the estimation of its parameters (Mahajan & Peterson, 1985). Using the Bass model in forecasting the diffusion of technological diffusion needs to estimate the parameters p , q, m the coefficient of imitation, coefficient of innovation and market potential respectively. Estimating the market potential term m has advanced recently because of the use of secondary sources, market surveys (Mahajan, Muller, & Bass., 1990), and expert judgement[16] (Souder & Quaddus, 1982). Since the Bass model (mixed-influence) has three parameters (p, q, m), the estimation of its parameters will require a time-series adoption data in a three periods minimum[17]. F. M. Bass (1969) suggested the Ordinary Least Square (OLS) for the parameters estimation. The OLS procedure estimates parameters by taking the discrete form of the mixed-influence model (equation 4).

From the equation (4), mixed-influence model

$$\frac{dN(t)}{d(t)} = (p + qN(t))\,[m - N(t)]$$

Re-arranging the above mixed-influence equation into discrete form yields:

[16] This method can be used when there is no prior data available. A good example is algebraic estimation where experts determine the market size, the peak time and amount of adoption at the peak (Bass, 1969)

[17] Empirical studies suggested that estimation of parameters and its associated forecasts are sensitive to number of periods. Bayesian estimation procedures considered the update of data-points when new data become available as the diffusion process is ongoing.

$$N_{(t+1)} - N_t = pm + (q - p)N(t) - \frac{q}{m}N^2(t) \qquad \text{Eq. (17)}$$

$$N_{(t+1)} - N_t = \propto_1 + \propto_2 N(t) + \propto_3 N^2(t) \qquad \text{Eq. (18)}$$

Where $\propto_1 = pm \quad \propto_2 = q - p \quad \propto_3 = -\frac{q}{m}$

Having the regression coefficients $\propto_1$, $\propto_2$, and $\propto_3$, by using the ordinary least square regression analysis, the parameter p, q, m can be obtained as follows:

$$\hat{p} = \frac{-\hat{\propto}_2 \pm \sqrt{\hat{\propto}_2{}^2 - 4\,\hat{\propto}_1\hat{\propto}_3}}{2} \qquad \text{Eq. (19)}$$

$$\hat{q} = \frac{-\hat{\propto}_2 \pm \sqrt{\hat{\propto}_2{}^2 - 4\,\hat{\propto}_1\hat{\propto}_3}}{2} \qquad \text{Eq. (20)}$$

$$\hat{m} = \frac{-\hat{\propto}_2 \pm \sqrt{\hat{\propto}_2{}^2 - 4\,\hat{\propto}_1\hat{\propto}_3}}{2\,\hat{\propto}_3} \qquad \text{Eq. (21)}$$

The OLS estimation procedure is simple to use, however it has three shortcomings (Schmittlein & Mahajan, 1982). First, due to the high degree of multicollinearity between regressors $N(t)$ and $N^2(t)$ in equation (14), there is high chance of having parameters estimates that are unstable or possess inappropriate signs. Second, the OLS estimation procedure does not provide standard errors for the estimated parameters which make it difficult to assess its statistical implication. Third, the time-interval bias exist because the discrete time-series data is used in estimating the continuous model.

As an alternative to overcome these shortcomings, Schmittlein & Mahajan (1982) proposed a maximum likelihood estimation procedure (MLE). The MLE procedure offers the computation of approximate standard errors of p, q, m parameters, but it also has limitations since it considers only sampling errors and ignores all other errors which in practice drives the diffusion pocess (Mahajan, Muller, & Bass., 1990). Srinivasan & Mason (1986) presented the Non-Linear Least Square estimation (NLS) procedure to overcome the shortcomings of MLE procedure by using an additive error term to model errors not included in the MLE procedure presented by Srinivasan & Mason (1986). The formulation of NLS procedure starts from the Bass model's density function of adoption at time t, $n(t)$.

$$\frac{n(t)}{(1-N(t)} = p + qN(t),$$

$$n(t) = p + qN(t) * (1 - N(t),$$

The above equation has the cummulative distribution function as follows (Schmittlein & Mahajan, 1982):

$$N(t) = \frac{(1-e^{-(p+q)t})}{(1+\frac{q}{p}e^{-(p+q)t})} \qquad \text{Eq. (22)}$$

From the equation (18), the future adopters of an innovation (sales), S_t in the time interval $(t, t+1)$ will be given by:

$$S_t = m(N_{t+1} - N_t) + \varepsilon_{t+1} \qquad \text{Eq. (23)}$$

or

$$S_t = m\left(\frac{(1-e^{-(p+q)t+1})}{(1+\frac{q}{p}e^{-(p+q)t+1})} - \frac{(1-e^{-(p+q)t})}{(1+\frac{q}{p}e^{-(p+q)t})}\right) + \varepsilon_{t+1} \qquad \text{Eq. (24)}$$

Where ε_{t+1} is an error term added to model errors (sampling errors and impact of excluded variables such as marketing push) not included in the MLE procedure presented by Srinivasan & Mason (1986).

In this research, we estimated the model parameters by using Logistic Substitution Model II[18] (LSM2) developed by International Institute for Applied Science (IIASA). LSM2 is a software package used to examine the dynamics and growth of a technology and how it interacts with other technologies (IIASA, 2019). The estimates were confirmed with the Loglet Lab 4.

[18] LSM2 software package is available for free online at http://www.iiasa.ac.at/web/home/research/researchPrograms/TransitionstoNewTechnologies/download.en.html

4 DATA ANALYSIS

This section discusses the models that were developed to support the analysis, the equations used, and justifications for the assumptions and scenarios that have been studied. The parameter estimation methods are vital in fitting the models to empirical data (Mahajan & Peterson, 1985), based on the parameter estimation issues raised in the literature review, this research estimated the parameters using the non-linear least square method built in IIASA-Logistic Substitution Model II and LogLet Lab 4.

4.1 Gompertz Model

Both Gompertz and Logistic model parameters for both Japan and Germany are estimated (Table 2) by IIASA-Logistic Substitution Model II using annual installed and cumulative installed solar power capacities span from 1990-2017 (IEA-PVPS, 2019). Table 1 presents the estimation results for Gompertz and Logistic. It is fair to say that the models fit the data very well according to the reported values of R^2 and estimated parameter signs.

	Gompertz					Logistic				
	K	*Tm (γ)*	*Delta T (ΔT)*	R^2	*MAPE*	*K*	*Tm (γ)*	*Delta T (ΔT)*	R^2	*MAPE*
Japan	90.143	2016	10.996	0.995	0.45	60.28	2015	6.528	0.997	0.35
	44.501	2014	3.976	0.98	0.78	42.132	2014	3.926	0.984	0.68
Germany	44.501	2010	7.155	0.996	0.19	42.132	2011	6.285	0.999	0.11
	90.143	2014	21.77	0.965	0.61	60.28	2013	12.729	0.967	0.53

Table 1. Gompertz and Logistic models parameter estimates for Japan and Germany

* Based on IIASA-Logistic Substitution Model II

However, for the case of Japan when not restricting the IIASA-Logistic Substitution Model II to different saturation levels, naturally the Gompertz model predicted the saturation level to be 90.143 GW while the Logistic model had a corresponding saturation level of 60.28 GW. This observation entails that the saturation level of cumulative installed solar power capacity in Japan cannot be below 60.28 GW or higher than 90.143 GW, otherwise the saturation assigned should be well examined.

On the basis of Gompertz model, Figure 4-1 presents the future trends of cumulative installed solar PV capacity in Japan until 2040 for selected saturation levels of 90.143 GW, and 44.501 GW[19]. In this research, based on the results of IIASA-Logistic Substitution Model II parameter estimations[20] the further analysis will primarily be based on the Gompertz model at a saturation level of 90.143 GW solar PV installed capacity. Recalling equation (7): $\frac{dN(t)}{d(t)} = \overline{N} * e^{-a*e^{-bt}}$ where; $\frac{dN(t)}{d(t)}$ representing cumulative installed solar PV at a period time *t*.

$$\frac{dN(t)}{d(t)} = 90.143\ e^{-10.999*e^{0.3066t}}$$

where time *t* is 1 for 1992, 2 for 1993, 3 for 1994 and 49 for 2040.

[19] 44.501 GW was significant to Germany (R^2=0.996), it is worthwhile to examine this saturation level for the Japan case also.

[20] The parameter estimation was done based on the Non-Least Square method.

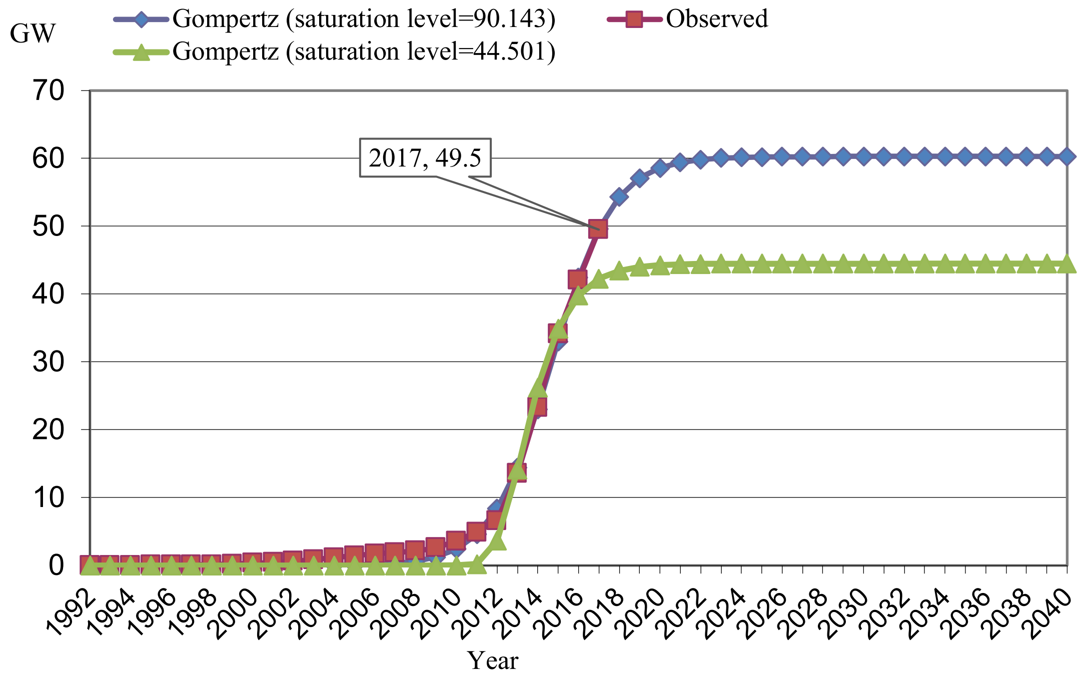


Figure 4-1.The Gompertz model's cumulative installed Solar PV power (1992-2040) - Japan

From the analysis of this research, it is revealed that inflection point (*Tm=2016.04*) of the diffusion curve occurred in 2016-2017 (Figure 4-2). This means that the rate of growth of installed solar PV capacity increased until 2016 and then started to decline thereafter. The installed capacity trend in Japan shows that in 2020 there will be 70.12 GW solar PV capacity installed (Figure 4-3). Also the trend shows that the growth rate of installed capacity will continue to decline until 2077 where it will eventually stops, provided that the technological innovation system (TIS) for solar PV in Japan remains the same (no revitalization) to not stimulate the diffusion process.

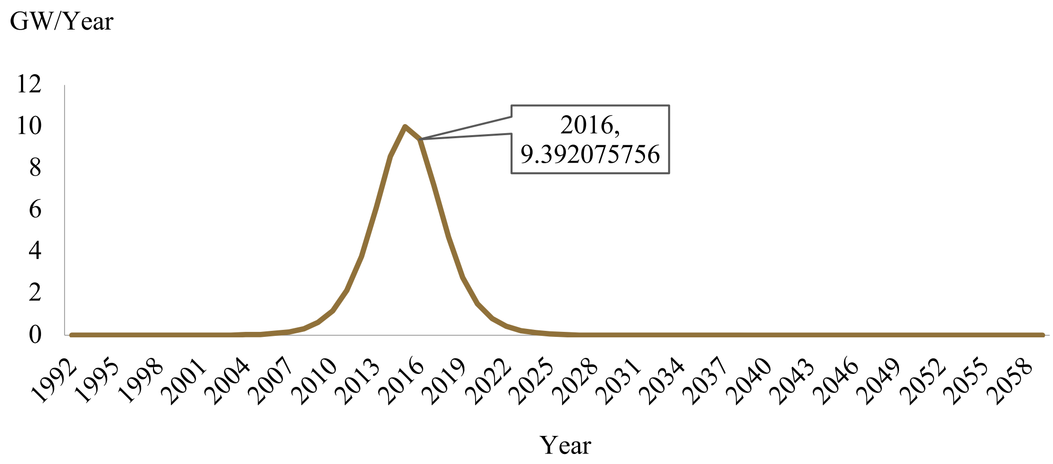


Figure 4-2. The Gompertz model's rate of change - Japan

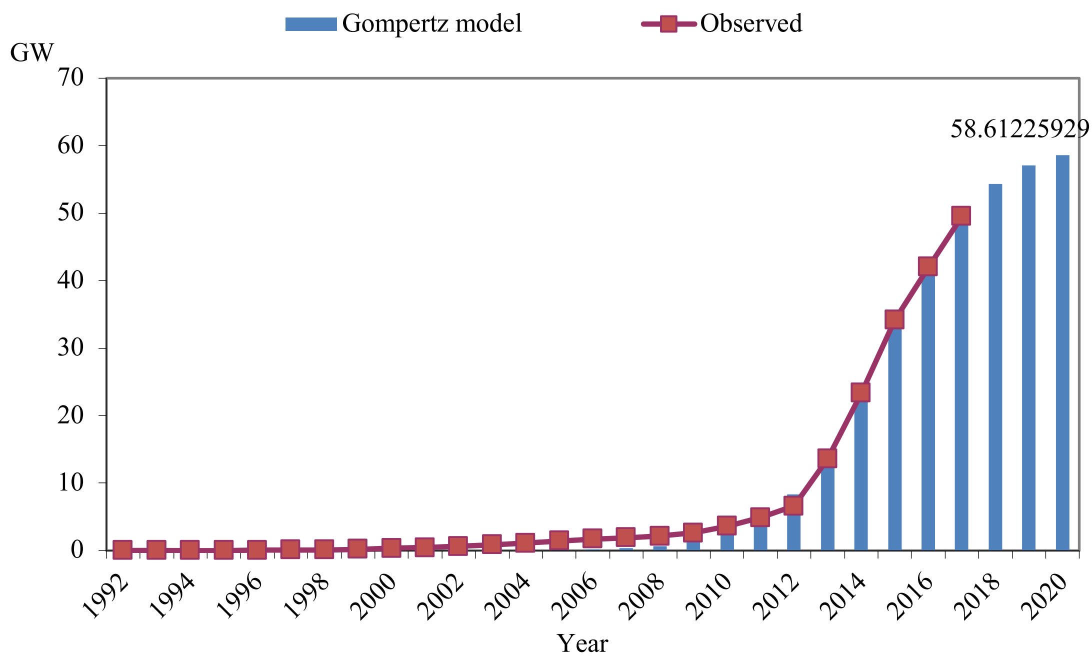


Figure 4-3. The Gompertz model's cumulative installed Solar PV power from (1992-2020) - Japan

For the case of Germany, when not restricting the IIASA-Logistic Substitution Model II to saturation levels, naturally the Gompertz model predicted the saturation level to be 44.501 GW (Table 1) while the Logistic model had a corresponding saturation level of 42.132 GW. This observation entails that the saturation level of cumulative installed solar power capacity in Germany cannot be below 42.132 GW or higher than 44.501 GW, otherwise the saturations assigned should be well examined.

On the basis of Gompertz model, Figure 4-4 presents the future trends of cumulative installed solar PV capacity in Germany until 2040 for selected saturation levels of 44.501 GW, and 90.143 GW[21]. In this research, based on the results of IIASA-Logistic Substitution Model II parameter estimations[22] the further analysis will primarily be based on the Gompertz model at a saturation level of 44.501 GW solar PV installed capacity. Again, recalling equation (7): $\frac{dN(t)}{d(t)} = \overline{N} * e^{-a*e^{-bt}}$ where; $\frac{dN(t)}{d(t)}$ representing cumulative installed solar PV at a period time *t*.

$$\frac{dN(t)}{d(t)} = 44.501\ e^{-6.437*e^{0.3709t}}$$

where time *t* is 1 for 1990, 2 for 1992, 3 for 1993 and 51 for 2040.

[21] 90.143 GW was significant to Japan (R^2=0.965), it is worthwhile to examine this saturation level for the Germany case also.

[22] The parameter estimation was done based on the Non-Least Square method.

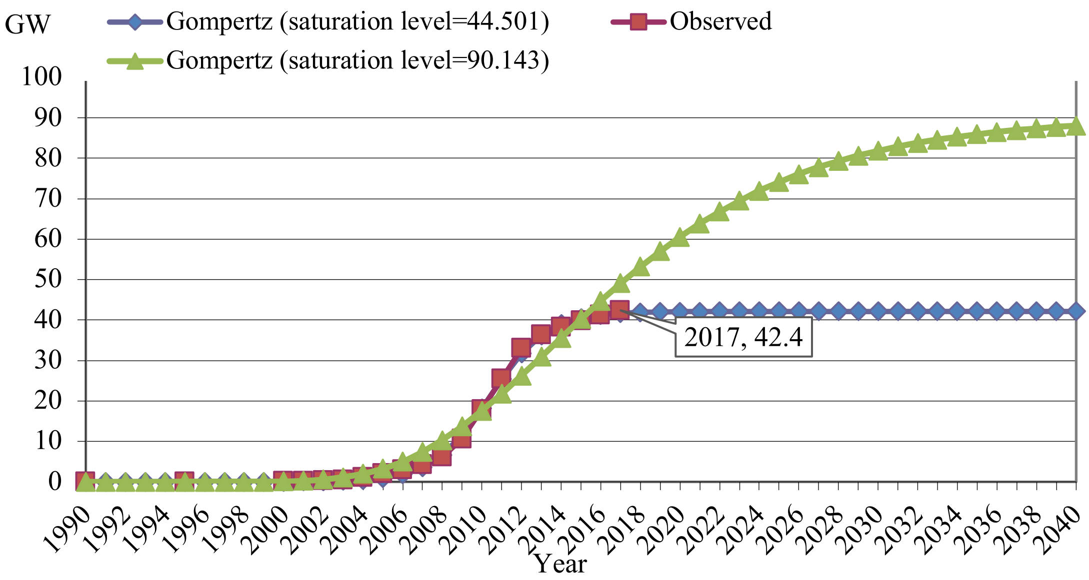


Figure 4-4. The Gompertz model's cumulative installed Solar PV power (1990-2040) - Germany

From the analysis of this research, it is revealed that inflection point (*Tm=2010.13*) of the diffusion curve occurred in 2010-2011 (*Figure 4-5*). This means that the rate of growth of installed solar PV capacity increased until 2010 and then started to decline thereafter. The installed capacity trend in Japan shows that in 2020 there will be 44 GW solar PV capacity installed (*Figure 4-6*). Also the trend shows that the growth rate of installed capacity will continue to decline until 2050 where it will eventually stops, provided that the technological innovation system (TIS) for solar PV in Japan remains the same (no revitalization) to not stimulate the diffusion process.

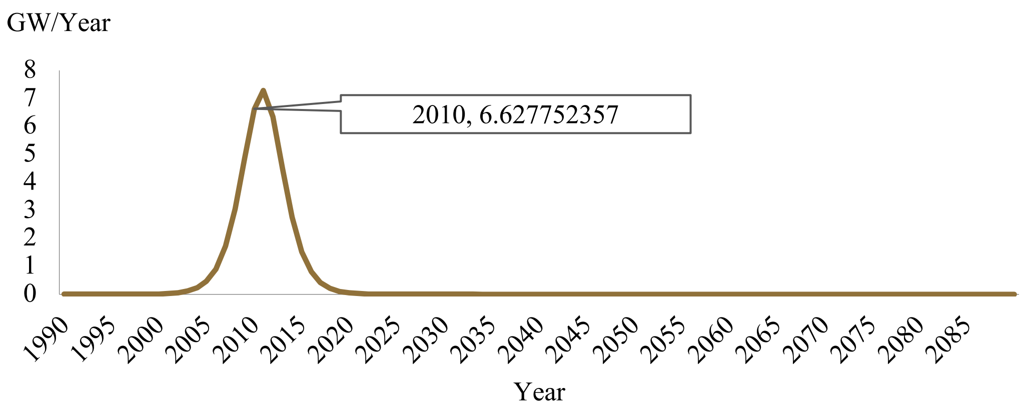


Figure 4-5. The Gompertz model's rate of change - Germany

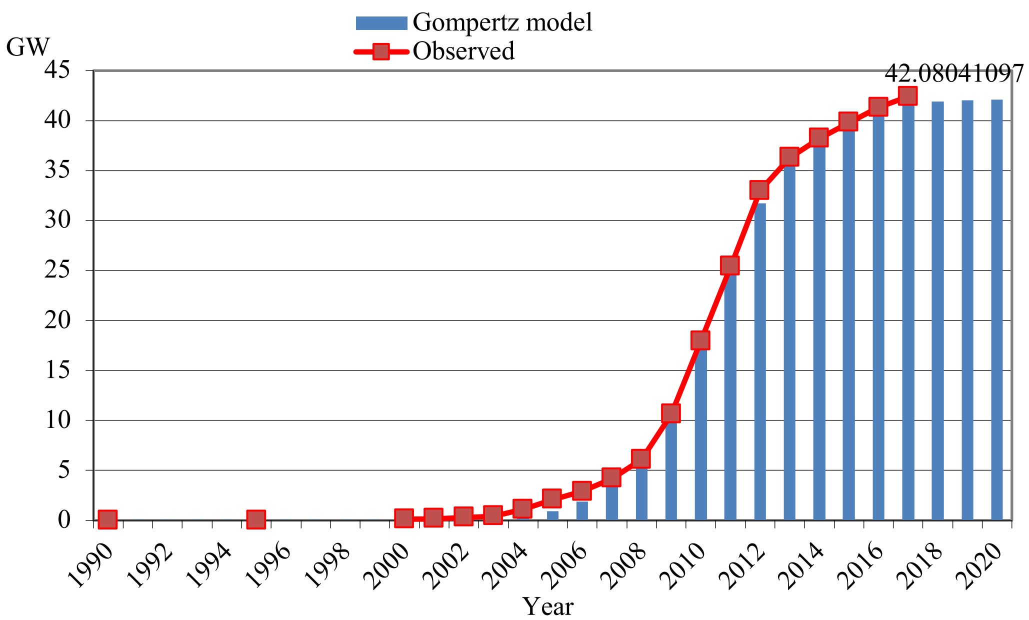


Figure 4-6. The Gompertz model's cumulative installed Solar PV power from (1990-2020) – Germany

The results reported in Table 1 show that; Japan will take about 11 years (*delta T=10.996*) to move from 10% to 90% of the 90.143 GW saturation level. Also, it will take about 22 years (*delta T=21.77*) for Germany ($R^2=0.965$) to achieve the 90.143 GW of solar PV installed capacity predicted for Japan ($R^2=0.995$). Figure 4-7 presents cumulative installed Solar PV power for the saturation level of 90.143 GW for Japan and Germany.

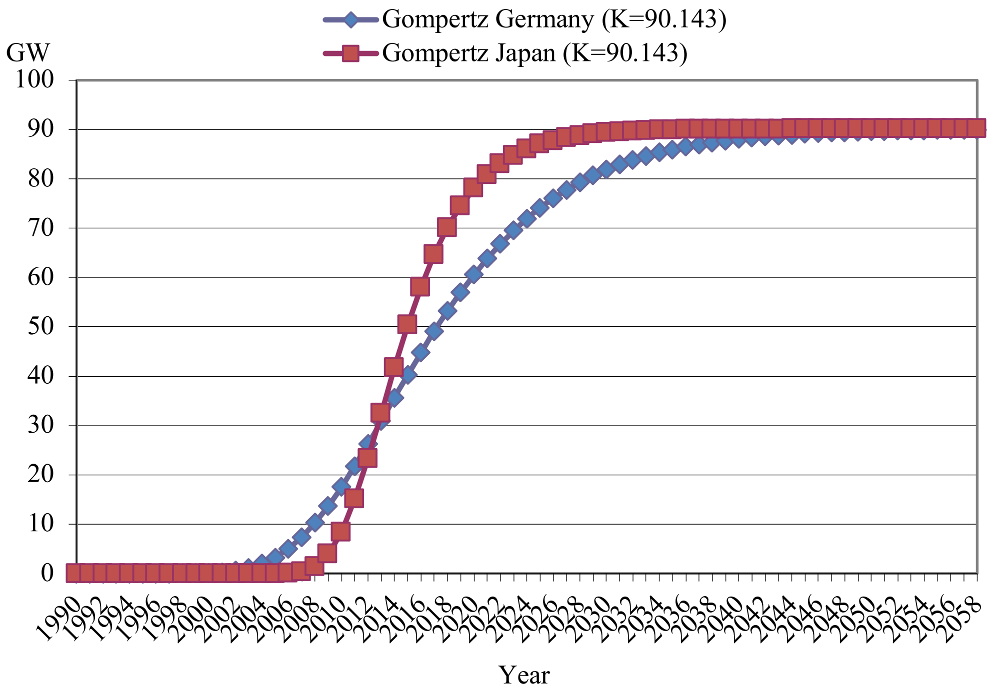


Figure 4-7. The Gompertz model's cumulative installed Solar PV power (1990-2058) K=90.143 – Japan and Germany

The fastest Japan's diffusion rate is also proved when restricting its saturation level to 44.501 GW. From the estimation results reported in Table 1; Japan will take about 4 years (*delta T=3.976*) to move from 10% to 90% of the 44.501 GW saturation level, while for Germany ($R^2=0.996$) it will take about 7 years (*delta T=7.155*) to achieve the 44.501 GW of solar PV installed capacity. *Figure 4-8* presents cumulative installed Solar PV power for the saturation level of 44.501 GW for Japan and Germany.

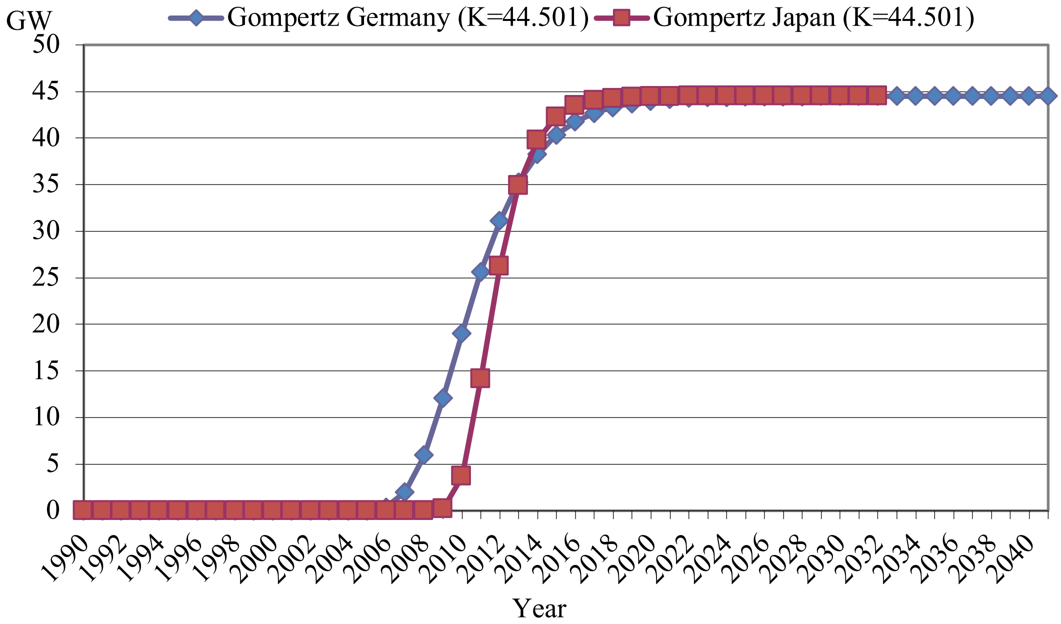


Figure 4-8. The Gompertz model's cumulative installed Solar PV power (1990-2040) K=44.501 – Japan and Germany.

4.2 Bi-Logistic Model

On the basis of Logistic model, *Figure 4-9* presents the future trends of cumulative installed solar PV capacity in Japan until 2040 for selected saturation levels of 60.28, and 42.132 GW[23]. In this research, based on the results of IIASA-Logistic Substitution Model II parameter estimations[24] the further analysis will primarily be based on the Logistic model at a saturation level of *K*= 60.28 GW solar PV installed capacity. Recalling equation (23): $N(t) = \frac{K}{1+e^{(-\propto t-\beta)}}$ where; $N(t)$ representing cumulative installed solar PV at a period time *t* which is 1 for 1992, 2 for 1993, 3 for 1994 and 49 for 2040.

[23] 42.132 GW was significant to Germany (R^2=0.999), it is worthwhile to examine this saturation level for the Japan case also.

[24] The parameter estimation was done based on the Non-Least Square method.

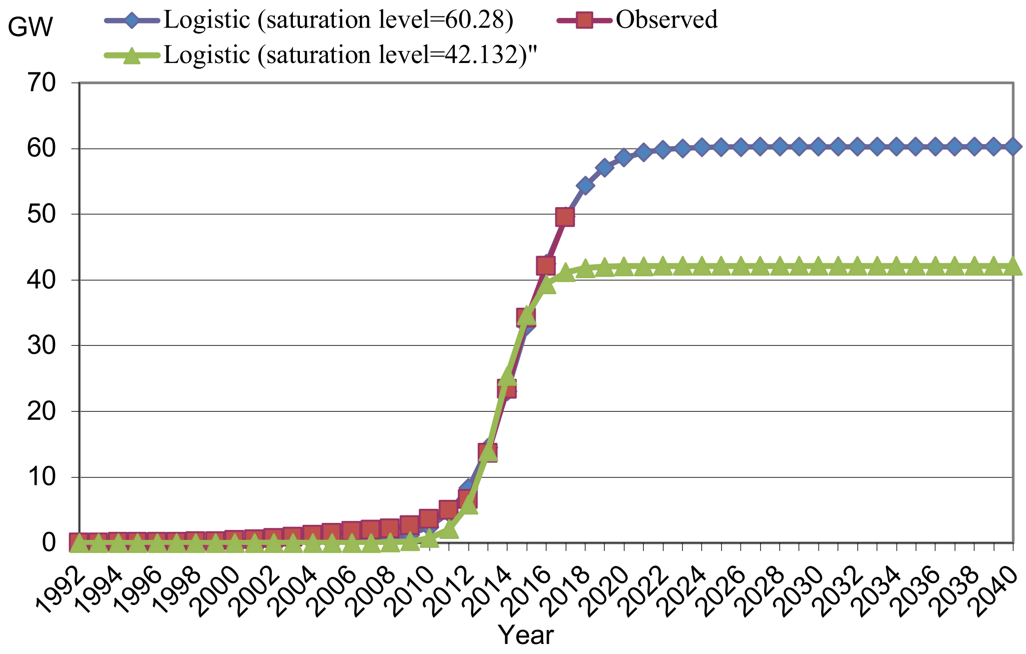


Figure 4-9. The Logistic model's cumulative installed Solar PV power (1992-2040) - Japan

From the analysis of this research, it is revealed that inflection point (*Tm=2015*) of the diffusion curve occurred in 2015-2016 (*Figure 4-10*). This means that the rate of growth of installed solar PV capacity increased until 2016 and then started to decline thereafter. The installed capacity trend in Japan shows that in 2020 there will be 58.6 GW solar PV capacity installed (*Figure 4-11*). Also the trend shows that the growth rate of installed capacity will continue to decline until 2067 where it will eventually stops, provided that the technological innovation system (TIS) for solar PV in Japan remains the same (no revitalization) to not stimulate the diffusion process.

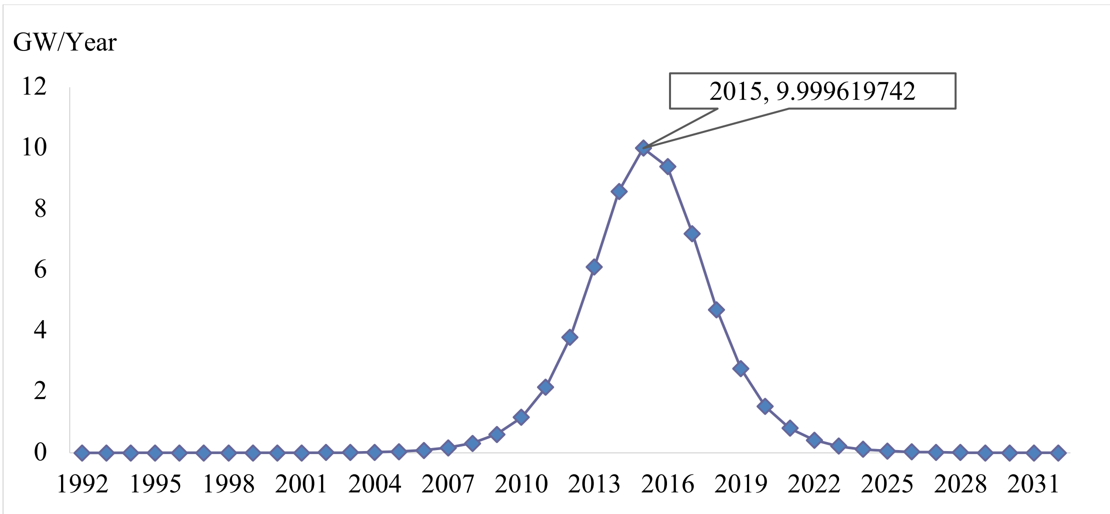


Figure 4-10. The Logistic model's rate of change - Japan

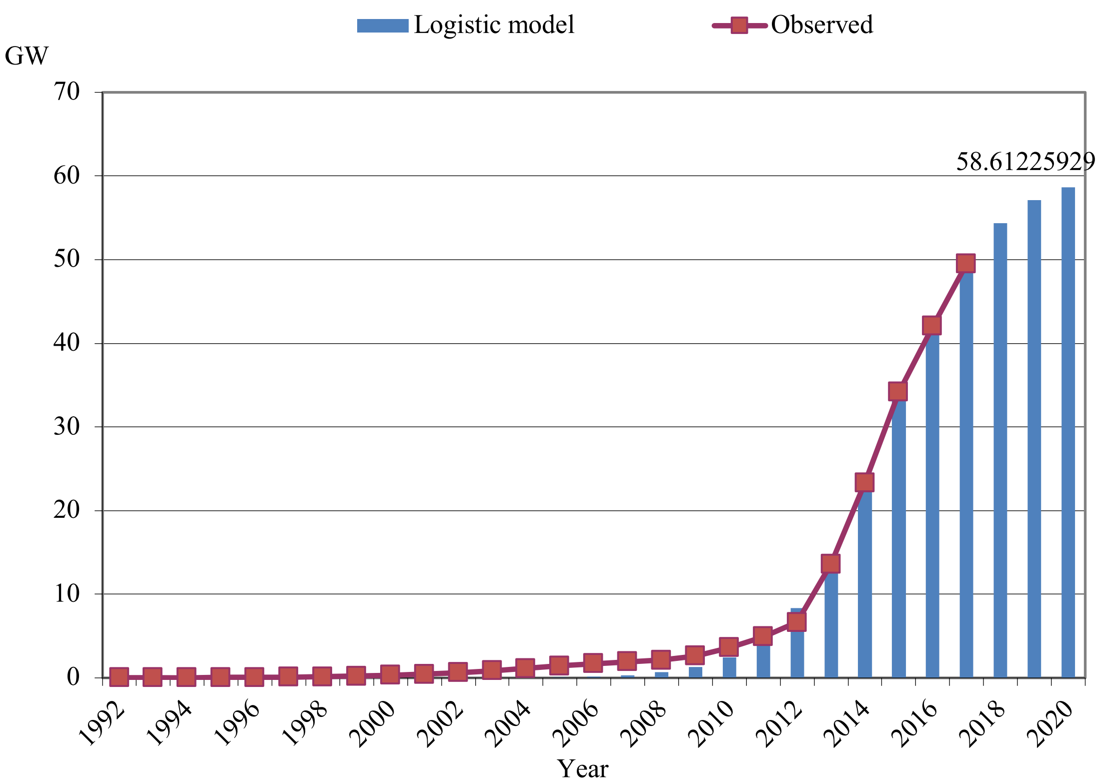


Figure 4-11. The Logistic model's cumulative installed Solar PV power from (1992-2020) - Japan

Deploying a Logistic model in Germany's case, Figure 4-12 presents the future trends of cumulative installed solar PV capacity in Germany until 2040 for selected saturation levels of 42.132, and 60.28 GW[25].

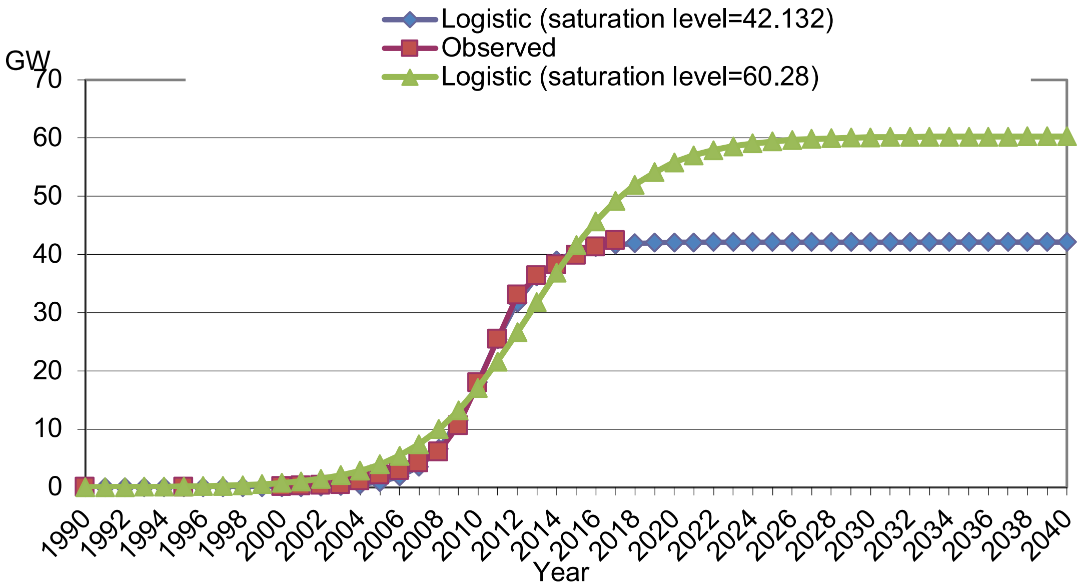


Figure 4-12. The Logistic model's cumulative installed Solar PV power (1990-2040) - Germany

Analysis reveals that, the inflection point (*Tm=2011*) of the diffusion curve occurred in 2011-2012 (Figure 4-13). This means that the rate of growth of installed solar PV capacity increased until 2011 and then started to decline thereafter. The installed capacity trend in Germany shows that in 2020 there will be 42.1 GW solar PV capacity installed (Figure 4-14). Also the trend shows that the growth rate of installed capacity will continue to decline until 2042 where it will eventually stops, provided that the technological innovation system (TIS) for solar PV in Japan remains the same (no revitalization) to not stimulate the diffusion process.

[25] 60.28 GW was significant to Japan (R^2=0.997), it is worthwhile to examine this saturation level for the Germany case also.

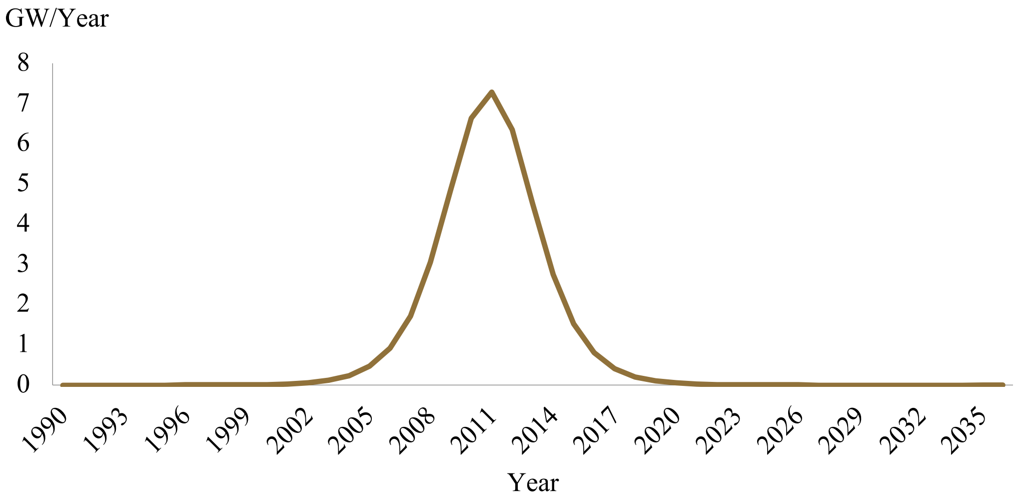


Figure 4-13. The Logistic model's rate of change - Germany

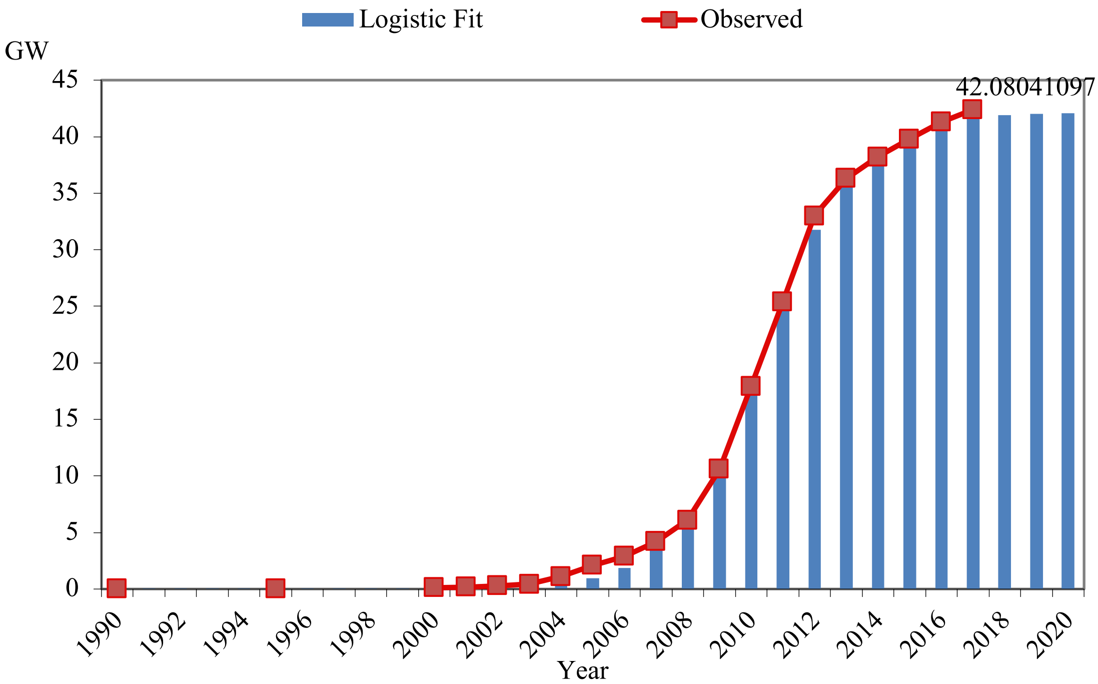


Figure 4-14. The Logistic model's cumulative installed Solar PV power from (1990-2020) - Germany

The results reported in Table 1 show that; Japan will take about 7 years (*delta T=6.528*) to move from 10% to 90% of the 60.28 GW saturation level. Also, it will take about 13 years (*delta T=12.729*) for Germany (*R^2=0.967*) to achieve the 60.28 GW of solar PV installed capacity predicted for Japan (*R^2=0.997*). *Figure 4-15* presents cumulative installed Solar PV power for the saturation level of 60.28 GW for Japan and Germany.

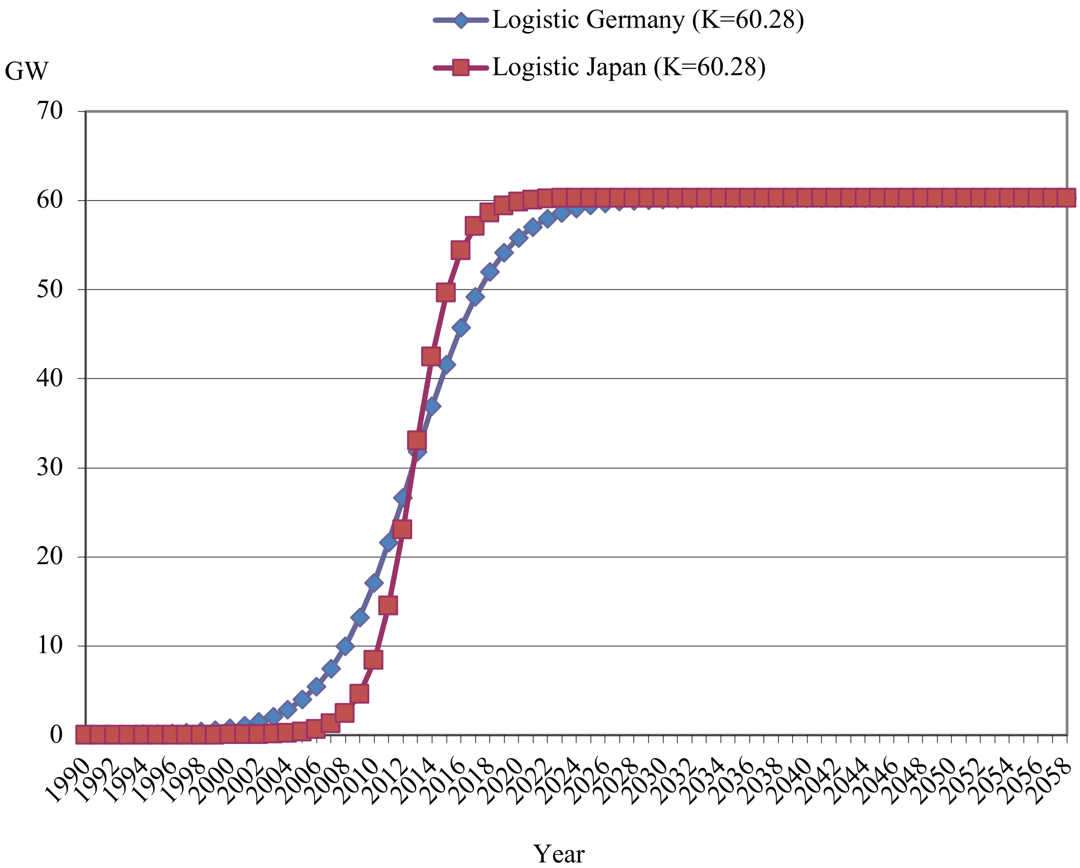


Figure 4-15. The Logistic model's cumulative installed Solar PV power (1990-2058) K=60.28 – Japan and Germany

The fastest Japan's diffusion rate is also proved when restricting its saturation level to 42.132 GW. From the estimation results reported in Table 1; Japan will take about 4 years (*delta T=3.926*) to move from 10% to 90% of the 442.132 GW saturation level, while for Germany (*R^2=0.999*) it will take about 6 years (*delta T=6.285*) to achieve the

42.132 GW of solar PV installed capacity. *Figure 4-16* presents cumulative installed Solar PV power for the saturation level of 42.132 GW for Japan and Germany.

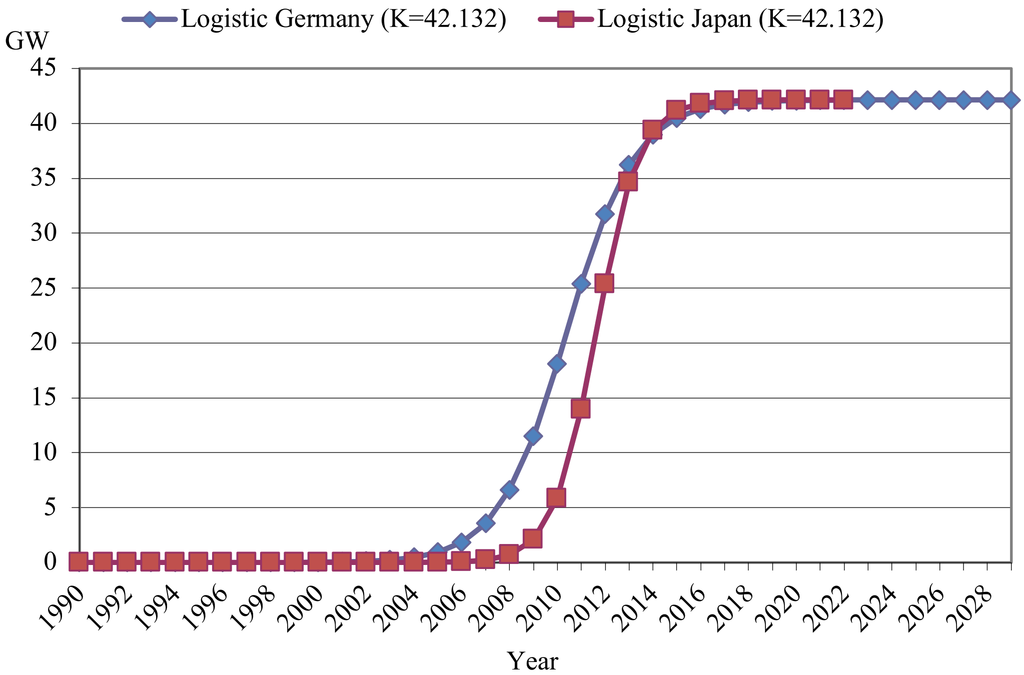


Figure 4-16. The Logistic model's cumulative installed Solar PV power (1990-2028)

K=42.132 – Japan and Germany

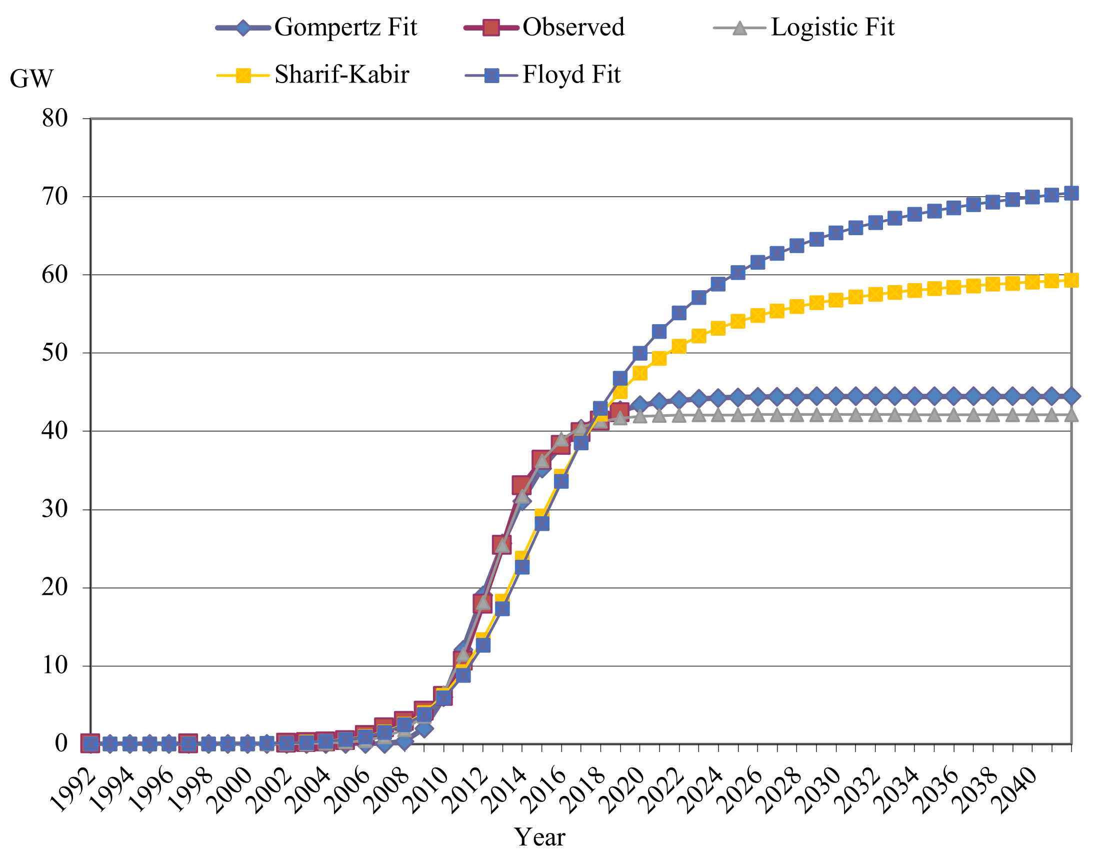


Figure 4-17. The Multiple models cumulative installed Solar PV power from (1992-2040) – Germany

4.3 Results Discussion: Gompertz and Bi-logistic

In order to select the best model that describes trajectories in Japan and Germany, as well as the saturation levels, we compared the actual and the predicated values of cumulative solar PV installed capacity. As reported in (Table 1), the MAPE values are in the range of 0.19-0.78 for Gompertz models 0.11-0.68 and for Logistic models. Both R^2 and MAPE suggests that Logistic model with saturation level of 60.28 GW fit the data better than the Gompertz equivalents for Japan (see Figure 4-9). Logistic model should be used to forecast the diffusion of solar PV in Japan. The same results for Germany also, Both R^2 and MAPE suggests that Logistic model with saturation level of 42.132 GW fit the data better than the Gompertz equivalents (see *Figure 4-12*).

Logistic model should be used to forecast the diffusion of solar PV in Germany. Figure 4-18 shows the forecasting of total installed solar PV capacity in Germany and Japan 2008-2023.

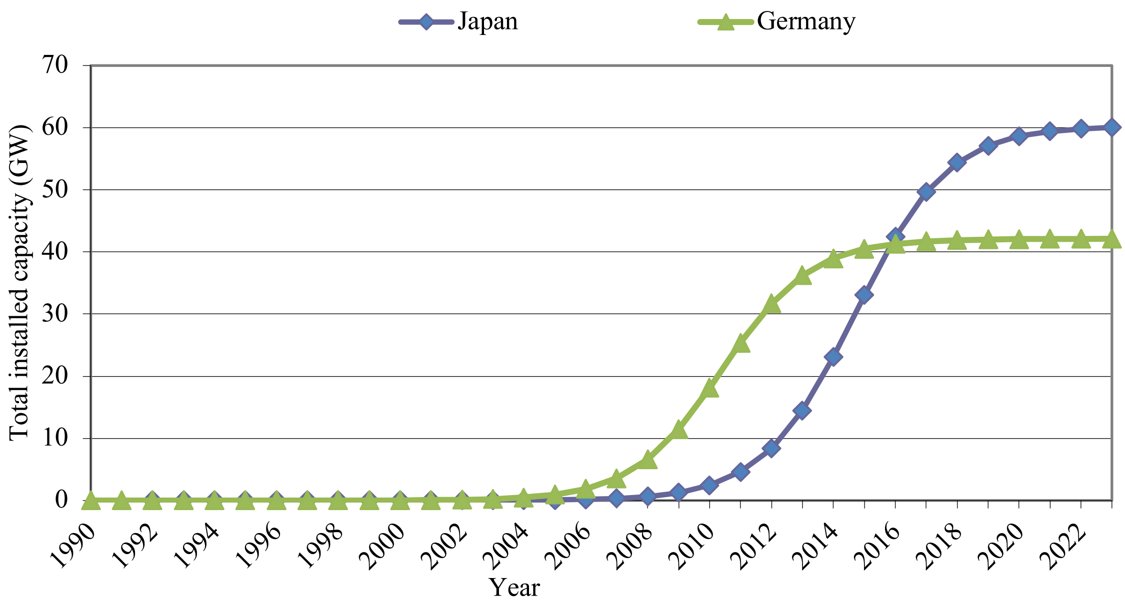


Figure 4-18. Total installed capacity forecast – Germany and Japan

4.4 Bass Diffusion Model

Bass model is another popular and powerful model used to study the diffusion patterns of different technological innovations (Mahajan & Muller, 1979). Bass model is simple and its parameters *p, q,* and *m* evidently distinguishing imitations and innovations of a technology as well as giving a clear understanding by of the diffusion process to be studied (Turk & Trkman, 2012).

The Bass model parameters for both Japan and Germany were estimated (*Table 2*) by the yearly installed and cumulative installed solar power capacities (IEA-PVPS, 2019). The Bass model equation (10); $\frac{dN(t+1)}{d(t+1)} = p[m - N(t)] + \frac{q}{m}N(t)[m - N(t)]$ was used to estimate the forecasts, wheres the rate of diffusion from 1990-2017 was calculated by $N_{(t+1)} - N_t$ and the maximum diffusion-point was calculated by equation (11); $t^* = (\frac{1}{(p+q)}) ln \frac{q}{p}$. The diffusion curves developed will be compared to the patterns suggested by Rogers, (2003), which stated that, the diffusion of an innovative product will follow the patterns shown in Figure 4-19.

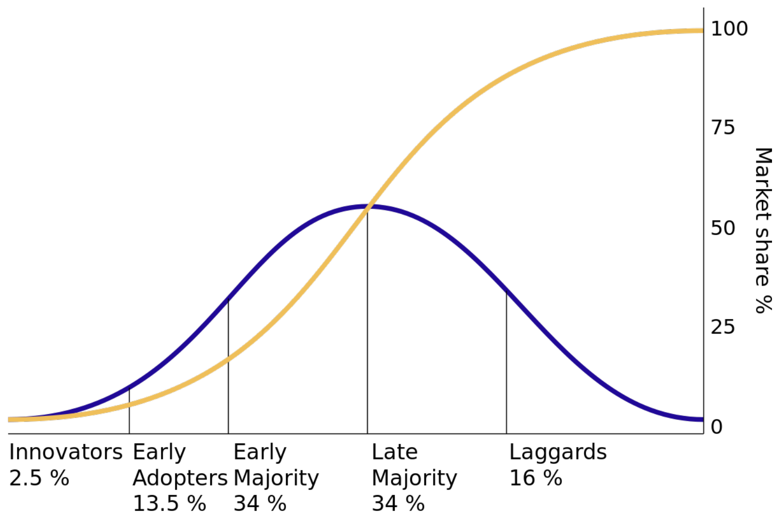


Figure 4-19. Rogers diffusion of innovation curve

(Rogers, 2003)

Country	Bass parameter estimates			
	p	*q*	*m*	R^2
Japan	0.000272	0.35695	90.143	0.965
	0.000212	0.39995	60.28	0.925
	0.00032	0.37295	120	0.998
Germany	0.00312	0.49509895	44.501	0.976
	0.00312	0.49509895	42.132	0.967
	0.0032017	0.5095099	60	0.999

Table 2. Bass model Parameter estimates for Japan and Germany (based on IIASA-Logistic Substitution Model II and own calculations)

From the model estimates reported in *Table 2*, the R^2 results are significant (model fit the data well) for Japan, and Germany except for the estimated *m* of 60.28 GW of installed solar power capacity in Japan. The parameters *p* and *q* estimated by IIASA-Logistic Substitution Model II are resembles those suggested by Changgui Dong; Benjamin Sigrin; Gregory Brinkman (2016). In diffusion of solar PV technology the *p* values ranges from 0.0025-0.0045, while those of *q* ranges from 0.3-0.7 (Changgui Dong; Benjamin Sigrin; Gregory Brinkman, 2016).

For the case of Japan, considering the saturation level (market potential) of 90.14 GW installed solar PV capacity, the highest diffusion rate was already seen in 2015. This means that, provided that the technological innovation system (TIS) for solar PV in Japan remained the same (no revitalization) to not stimulate the diffusion process, this might have been the actual peak of diffusion of solar PV installed capacity.

Our analysis shows that, in 2017 the diffusion rate reached the early stages of *late majority phase* in the diffusion curve. If the TIS for solar PV in Japan remains the same, in 2022 the diffusion rate will reach the *laggards phase* of the diffusion curve. Figure 4-20 shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Japan (m=90.14) based on the results of the estimated Bass model (for *m*=90.14),

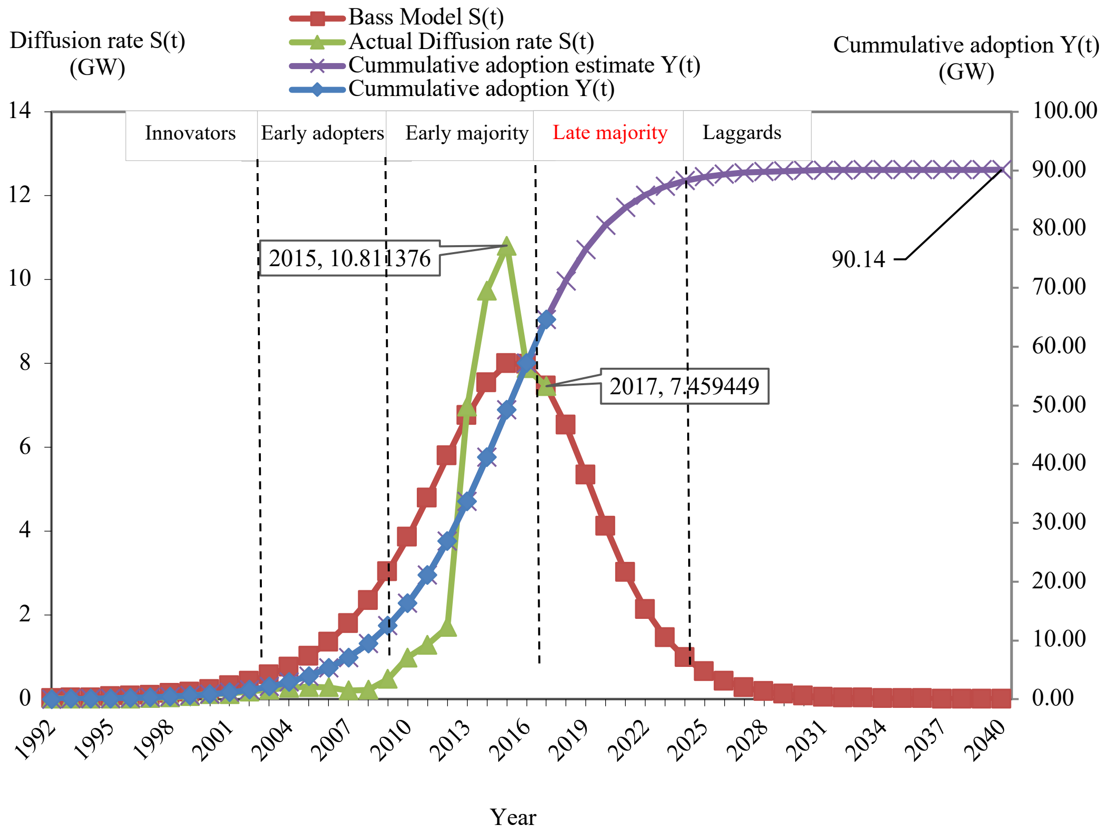


Figure 4-20. Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Japan (m=90.14).

We also tried to investigate another scenario of changing carrying capacity, study the diffusion curve and draw lessons from it. The IIASA-Logistic Substitution Model II gave a significant value of m = 60.28 saturation level for logistic growth model, it is worthwhile to see its associated diffusion curve in Bass model. Our analysis shows that, in 2017 the diffusion rate reached the late stages of *late majority phase* in the diffusion curve. If the TIS for solar PV in Japan remains the same, in 2018 the diffusion rate reached the *laggards phase* of the diffusion curve. *Figure 4-21* shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Japan based on the results of the estimated Bass model (for m=60.28).

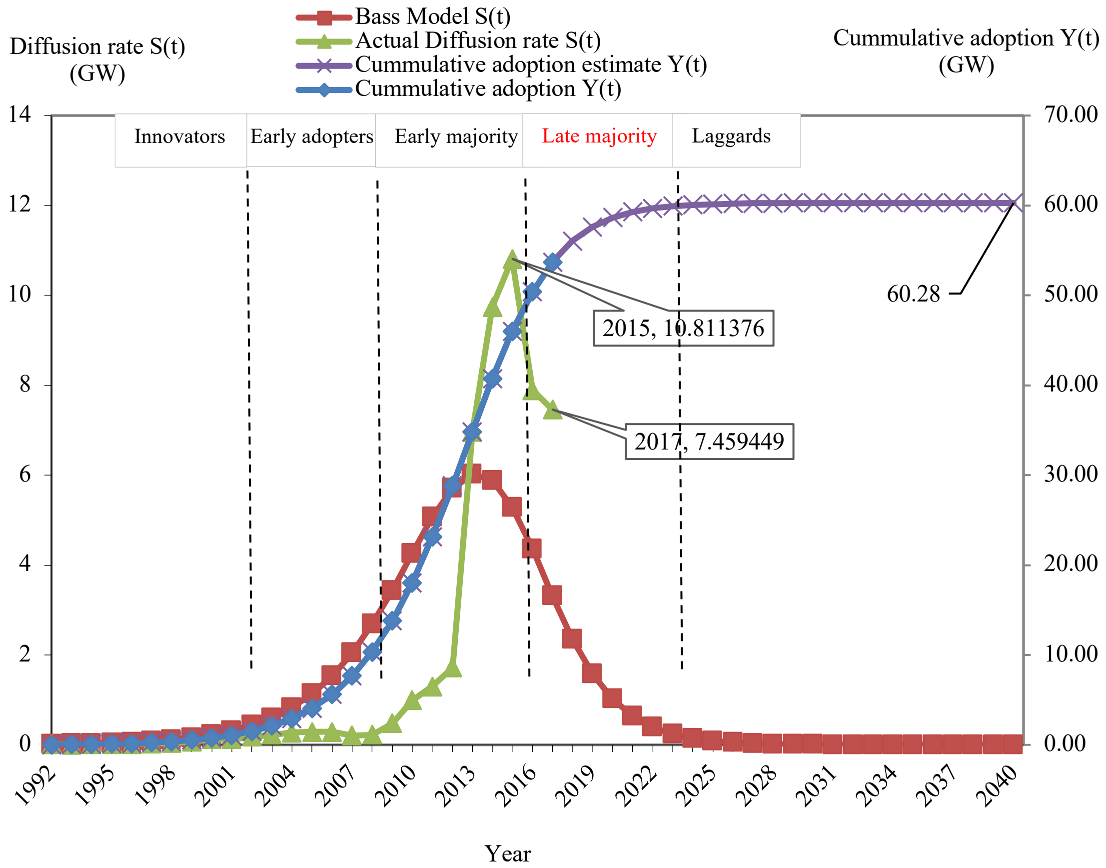


Figure 4-21. Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Japan (m=60.28).

Based on the authors' empirical findings, to better study the diffusion of solar PV in Japan, another scenario considered in this research is the saturation level of 120 GW installed solar PV capacity. Our analysis shows that, in 2017 the diffusion rate reached the middle stages of *late majority phase* in the diffusion curve. If the TIS for solar PV in Japan remains the same, in 2021 the diffusion rate reached the *laggards phase* of the diffusion curve. Figure 4-22 shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Japan based on the results of the estimated Bass model (for m=120).

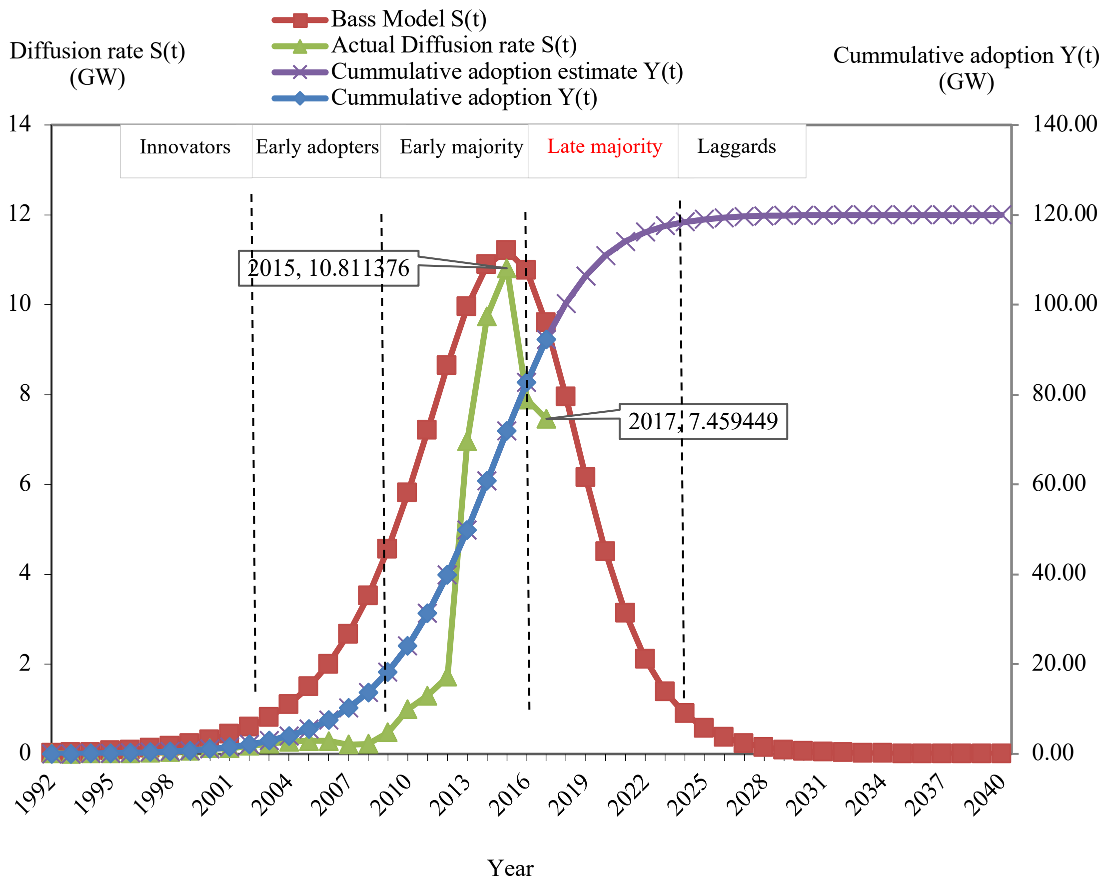


Figure 4-22. Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Japan (m=120).

For the case of Germany, considering the saturation level (market potential) of 44.501 GW installed solar PV capacity, the highest diffusion rate was already seen in 2012. This means that, provided that the technological innovation system (TIS) for solar PV in Germany remained the same (no revitalization) to not stimulate the diffusion process, this might have been the actual peak of diffusion of solar PV installed capacity.

Our analysis shows that, in 2017 the diffusion rate already reached the *laggards phase* in the diffusion curve. Figure 4-23 shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Germany based on the results of the estimated Bass model (for m=44.501).

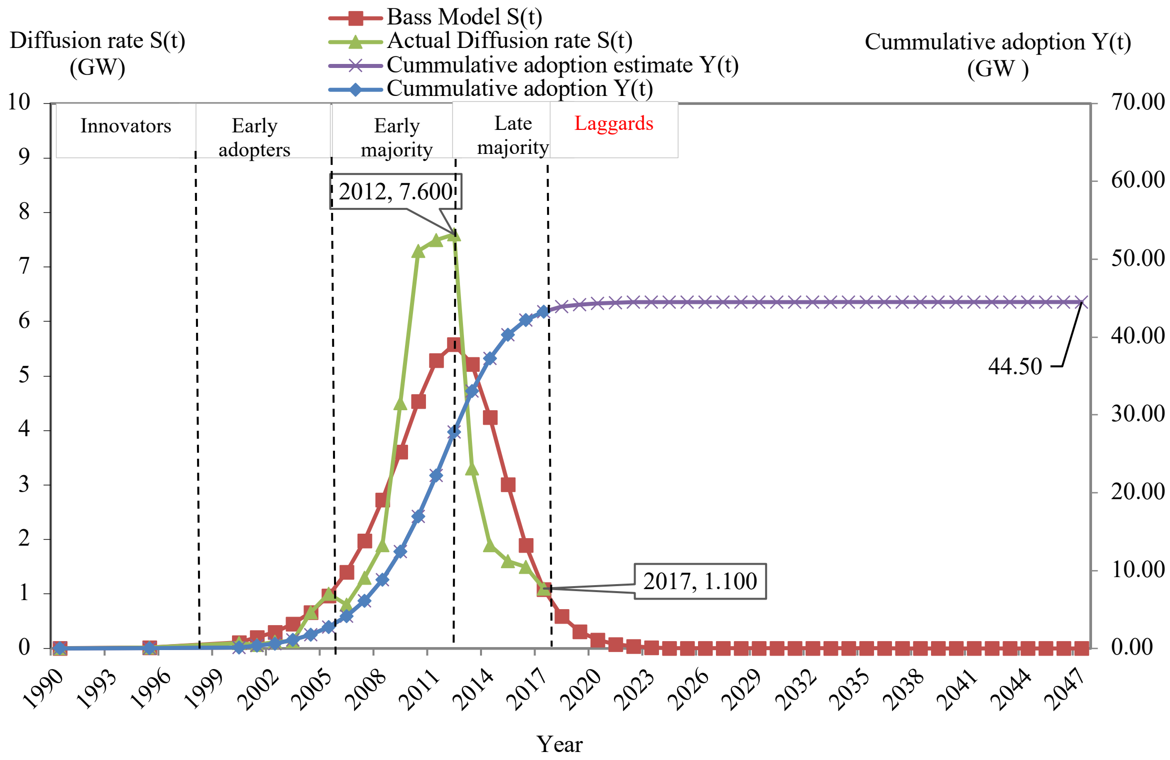


Figure 4-23 Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Germany (m=44.501).

We also tried to investigate another scenario of changing carrying capacity, study the diffusion curve and draw lessons from it. The IIASA-Logistic Substitution Model II gave a significant value of m = 42.132 saturation level for logistic growth model, it is worthwhile to see its associated diffusion curve in Bass model. Our analysis shows that, the results are considerably same as for the saturation level 44.501 because it is also in 2017 where the diffusion rate had already reached the *laggards phase* in the diffusion curve. *Figure 4-24* shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Germany based on the results of the estimated Bass model (for m=42.132).

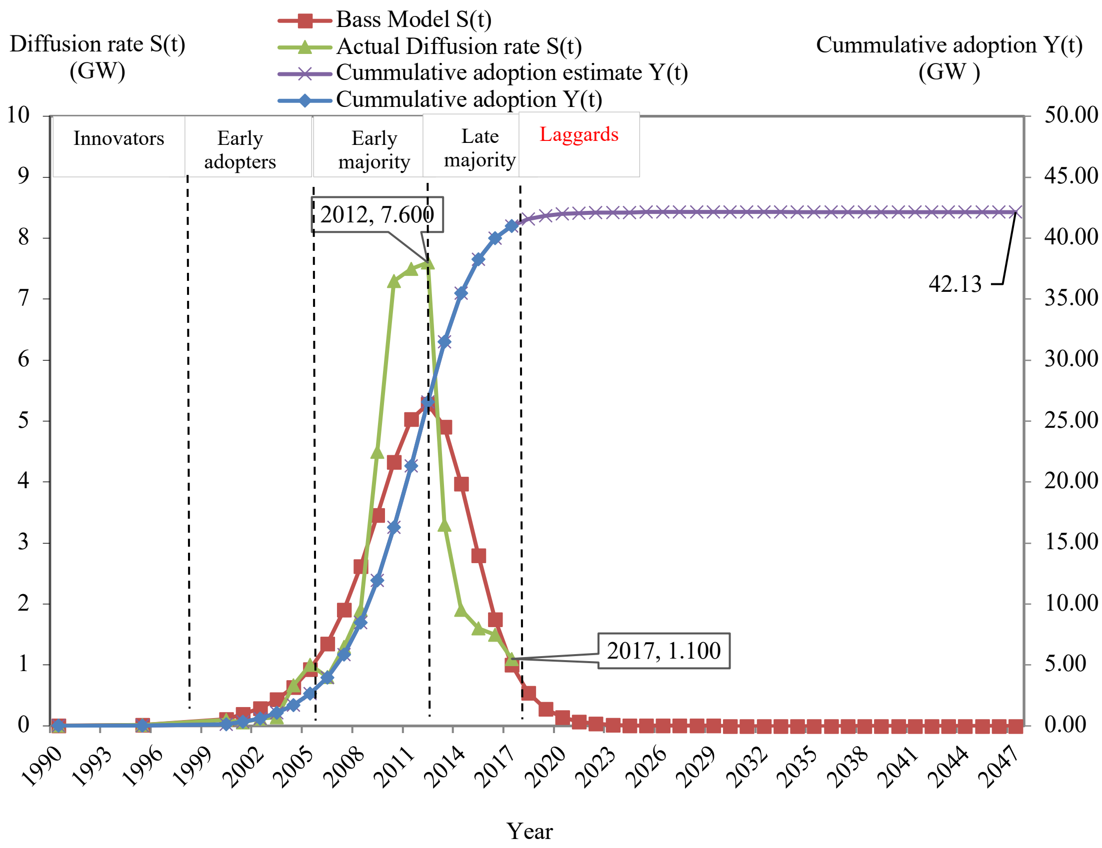


Figure 4-24 Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Germany (m=42.132).

Based on the authors' empirical findings, to better study and understand the diffusion of solar PV in Germany, another scenario considered in this research is the saturation level of 60 GW installed solar PV capacity. Our analysis shows that, in 2017 the diffusion rate would have been in *laggard phase* in the diffusion curve. *Figure 4-25* shows the Cumulative installed solar power capacity Y(t) and the diffusion rate S(t) for Germany based on the results of the estimated Bass model (for *m*=60).

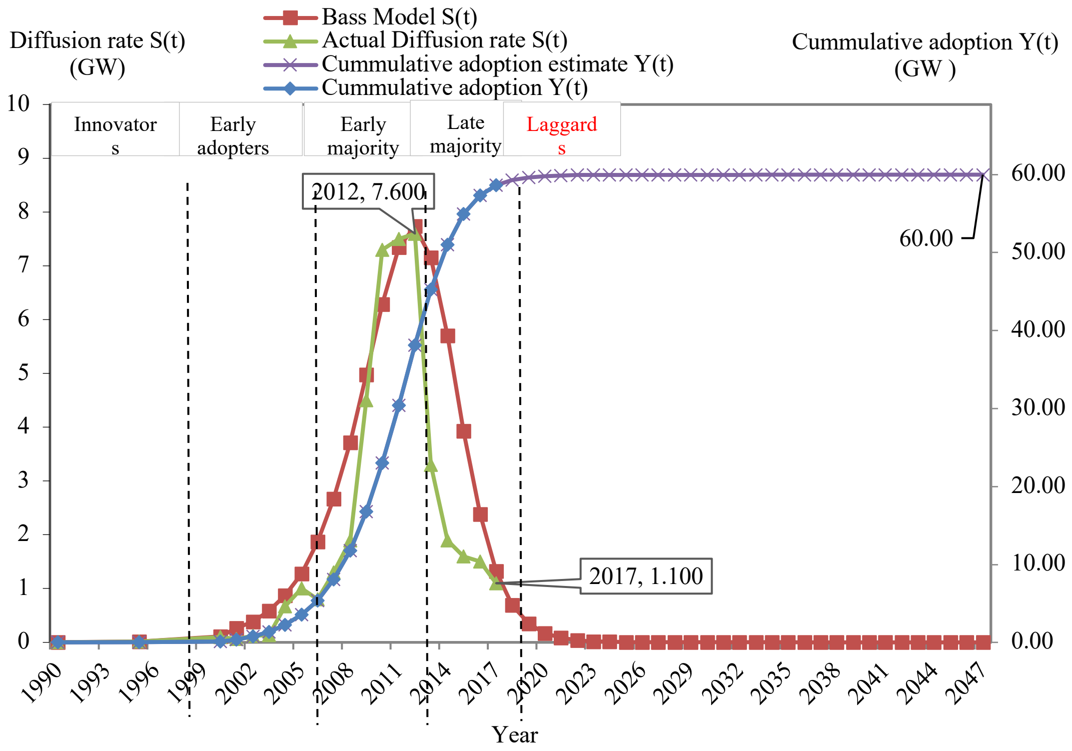


Figure 4-25 Cumulative installed solar power capacity Y(t), diffusion rate S(t) and Bass model estimates for Germany (m=60).

4.5 Results Discussion: Bass Model

Comparing the results shown by Bass models for both Japan and Germany and the actual collected data of installed solar PV shows that, Japan's adoption of solar PV is yet to capture the late majority (34%) who adopt an innovation after average number in a social system had adopted. This means that still a 16% (laggards) of potential adopters of an innovation in the social system are yet to adopt the solar PV technology. Figure 4-26 shows a steeper slope for Japan than Germany from 2012 to 2017. In Germany, solar PV adoption had already captured by the final adopters (laggards) of an innovation in a social system.

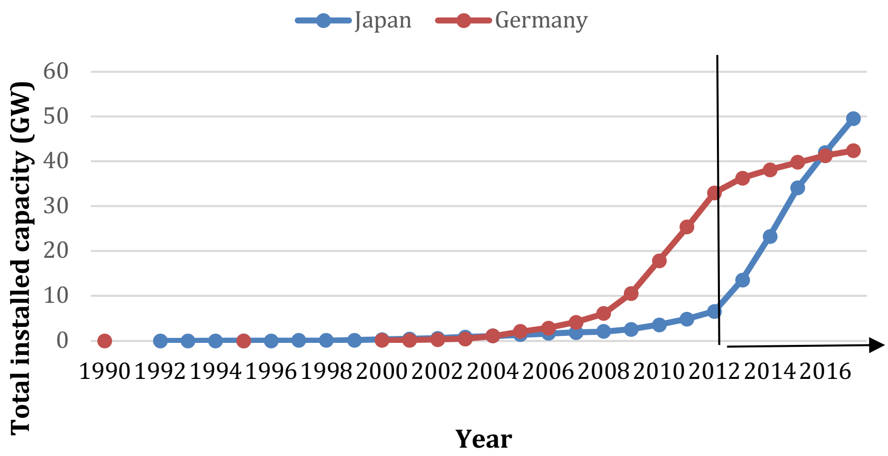


Figure 4-26. Solar PV adoption trajectories for Japan and Germany

4.6 Technological Innovation System (TIS)

The TIS for solar PV systems for technologically advanced countries (Japan and Germany) is formalized in Figure 4-27. The industry consists five types of actors: industrial organizations, BOS manufacturers (inverter, PCU, battery), BIPV manufacturers, PV cell/module/system manufacturers and material (silicon, electronic) suppliers. Material suppliers supply raw materials to user firms (PV cell/module/system and BOS manufacturers). Under the technological infrastructure, the solar PV system having solar array, battery, charge controller, D.C load, inverter and A.C load exposed to sunlight, needs functionally-oriented as well as generic technologies. Therefore solar PV technology depends on electrical engineering such as sensor technology, semiconductor, solar tracking, photochemistry and photovoltaic effect.

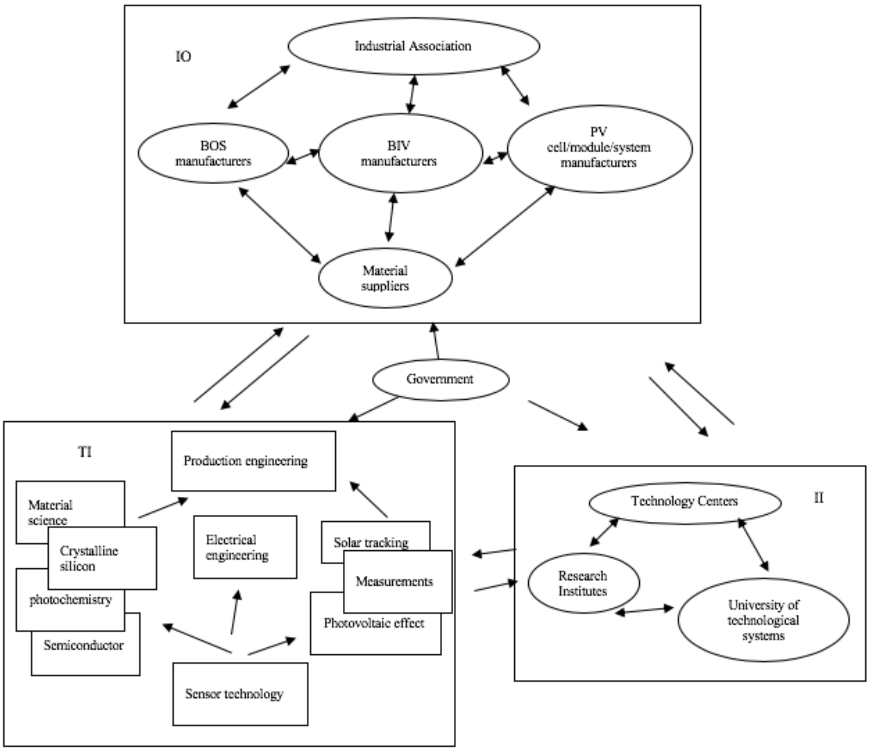


Figure 4-27. Technological Innovation System (TIS) for Solar PV systems

Source: (Carlsson & Stankiewicz, 1991)

4.6.1 Japan

At its embryotic stage, Japan started by having private firms such as Tohoku electric power doing in-house researches in solar cells after it was first invented in U.S in 1953. The government then started promoting new energies after the oil shock. As summarized in Table 3, the development of solar PV industry in Japan was mainly due to strong government intervaention through policy reforms[26] and pilot test projects. From 1992-2000 these test projects which created market demand, led to a total number of 507 systems (total 13470 kW) installed (IEA-PVPS, 2019). Also subsidy program for residential (1994-2000) led to to a total number of 58614 systems (216.5 MW)

[26] Sunshine and New sunshine project, RPS, and Feed-in Tariff.

installed (IEA-PVPS, 2019). Also, Monitoring Programme for Residential PV Systems encouraged the implementation of PV because 50% of the installation costs were subsidized (Jäger-Waldau, 2002).

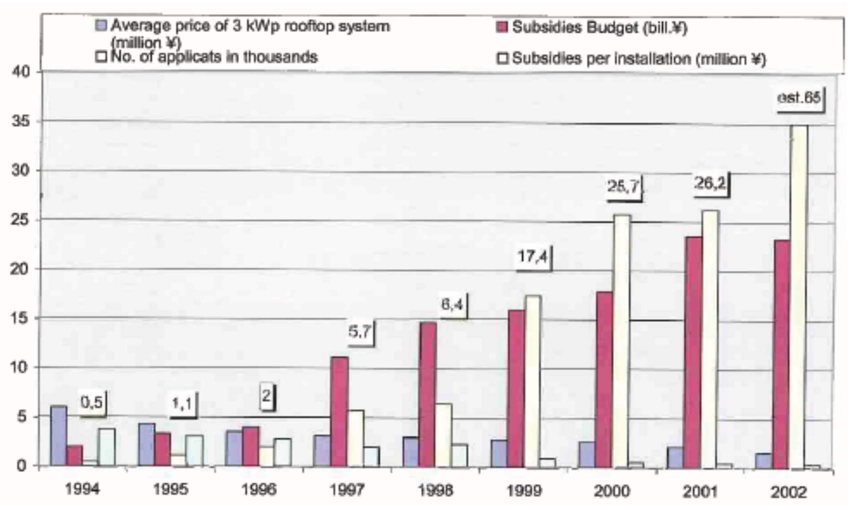


Figure 4-28 Increase of PV roof-top installation in Japan 1994-2002

Source: (IEA-PVPS, 2019)

	Embryo (before 1985	Infant (1986-1999)	Adolescent (after 2000
Industrial Organization (IO)	• Private industries entered the market such as Tohoku, Sharp, and Mitsubishi.	• Kuwano's solar power station (1992) • Overseas production • Foreign investors • Domestic market formation	• Foreign and domestic firms increased their presence

Institutional Infrastructure (II)	• Private companies had Solar PV focused technology centers • Sharp corporation R&D (1959)	• Strong investments in R&D by private firms	• Fukushima Renewable Energy Institute (2014) • National Renewable energy laboratory
Technological Infrastructure (TI)	• Solar cell invention (1953) • Solar cell prototype model (1955) • 1st PV system by Tohoku Electric (1958)	• Compact PV generation system (1992) • Photovoltaic Power Generation Technology Research Association (1990) • Demonstration projects	• Expansion of R&D activities
Government policy and program	• Sunshine project (1974) • Moon light project (1978) • Electricity utility industry law (1990)	• New sunshine project (1993) • Residential PV monitor (1994) • Net metering (1994) • Field test project (1992) •	• New power purchase scheme (2010) • FIT scheme (2011) • RPS (2003) • Subsidy program (2009) • Green electricity fund (2000)

Major interactions	• Promotion of researches in new energies	• Market penetration initiatives (1993)	• PV expo (2009) • University-Firm-firm R&D corporations
Bridging institutions	• NEDO	• METI • MoE • JPEA • J-PEC	• The government of Japan • NEF • AIST

Table 3. The development of Technological Innovation System (TIS) for solar PV – Japan

Source: Author's compilation

4.6.2 Germany

Germany has the same trends in TIS development for solar PV as Japan, as summarized in Table 4, the development of solar PV industry in Germany was mainly due to strong government intervaention through policy reforms as well as having a strong domestic market. The first solar cell research center in 1960s folowed by demostration projects paved the way for diffusion of solar PV technology.

	Embryo (before 1985	Infant (1986-1999)	Adolescent (after 2000
Industrial Organization (IO)		• More than 70 major PV installations (1990s) • Grid-connected Residential PV systems (mid 1990s)	

Institutional Infrastructure (II)	• Research centers conducting researches on solar • Fraunhofer Institute for Solar Energy Systems (1981)		• Fraunhofer Institute for Solar Energy Systems R&D
Technological Infrastructure (TI)	• Solar cell research (1960) • 1st Demonstration projects (1983)	• Knowledge transfer	
Government Policy		• 1000 roofs subsidy program (1991-95) • EEG (1990) • Electricity feed in law (1991) • Market stimulation project (1999) • Green tariffs (1996)	• Feed in Tariffs (2011) • Modified EEG (2000) • Renewable energy act (2000) • 100,000 roofs subsidy program (2003) •
Major interactions		• Establishment of team for CO_2 reduction	

Critical mass		• Cooperation and government commitment after Chernobyl accident (1986)	• Joint research projects in PV (2004)
Bridging institutions		• Government funding	

Table 4. The development of Technological Innovation System (TIS) for solar PV – Germany

Source: Author's compilation

4.6.3 Tanzania

Industrial organization (IO), involves the network of actors interacting to produce or buy a product. As a technology follower country, Tanzania don't produce solar PV panels and its related equipment unlike Japan and Germany. The Industrial Organization block have the following types of actors:

- Importers

  Involve big companies such as Mobisol® and Ensol® who import the solar modules to Tanzania. These companies have trained staff who do the design, installation and maintenance of solar system equipment and they are serving big markets such as government, tour companies and NGOs.

- Module Suppliers (Local wholesalers and Retailers)

  These 'dealers' are almost everywhere in the country, buy from importers but mainly serves households customers for small projects.

- Installers (small-system technicians)

Tanzania has some substantial amount technicians who received trainings through various interventions. They provide installations, and minor maintenance services to solar small systems.

- Users (Households, companies, government and NGOs)

  These are buyers of solar PV systems. They include corporate companies such tour operators, national parks as well as NGOs. Users of solar systems also involves small households in both rural (bigger part being off-grid) and urban areas.

Industrial networks are characterized as being more informal rather than formal such as stakeholders meetings, trade fairs and exhibitions. Tanzania Bureau of Standards (TBS) has developed minimum standards and installation guidelines for solar PV equipment and solar installations. The output of institutional infrastructure (II) is a group of trained people and research results which can be used by companies operating in the sector. For example; in between 2006 and 2016, TAREA and VETA[27] worked together to introduce the renewable energy curriculum to facilitate the diffusion of technical knowledge to more Tanzanian people, also VETA had introduced the short course programme on installation of renewable energy systems. In 1993, Resources for Solar Energy Technicians and Planners in East and Southern Africa conducted a solar training[28] at KSTF[29] in the northern part of Tanzania as part of an ongoing continental research at that time to create awareness and build capacity of local technicians but the technological system was not ready at that moment to take advantage of knowledge gained. For new opportunities created by innovation to be realized into economic activities the availability of pre-conditions is necessary [Carlsson, Jacobsson, Holmen,

[27] Vocational Education Training Authority
[28] Courses offered were; solar orientation, intensive solar electric installation, advanced solar electric courses
[29] Karagwe Solar Training Facility

Rickne, 2002]. At that time government didn't have special plans for rural electrification to make use of available knowledge gained same as for importers, there were no special conditions to facilitate them importing solar photovoltaics as a result, it created a 'structural tension' which when resolved makes progress possible. SolarNow[30] trained dealers throughout the country to design and market solar heating systems. As a result, technicians increased and created their own small-informal firms offering small solar systems installations using solar photovoltaics with the households being their main customers. But corporate companies or big solar systems projects use big solar companies 'importers' who have their own technicians and engineers for design, installations and maintenance. To the best of my knowledge, University of Dar es Salaam (UDSM) and Dar es Salaam Institute of Technology (DIT) are the only universities in Tanzania which offer renewable energy technology courses. Both universities have units which do researches and disseminate the information through various forms such as education, research publications and outreach-programmes[31]. This knowledge is expected to improve the performance of technological system for photovoltaics. Tanzania Commission for Science and Technology (COSTECH) as the prime driver of science, technology and innovation in Tanzania established to foster knowledge based economy through coordination of technological research activities where various actors in the industry meet formally and informally to share the technical knowledge via conferences, meetings, publications etc. There are other research institutes such as Small Industries Development Organization (SIDO), Tanzania Industrial Research and Development Organization (TIRDO), Tanzania Engineering

[30] A for profit social business with Dutch origin providing solar energy solutions

[31] SIDA/MEM-PV Project. Working with experts from the University of Dar es Salaam and TASEA, completed dozens of small solar heating systems installation training courses around the country and compiled a database of trained technicians.

and Manufacturing Design Organization (TEMDO) and Tanzania Bureau of Standards (TBS) which are as well providing the platform to contribute to the development of technological system for photovoltaics under renewable energy technologies through the same interactions between actors. Buni technology hub (innovation space) located in the capital, foster innovation and technology entrepreneurship through capacity building and mentoring programs and as results there are two ongoing projects[32] under the umbrella of renewable energy technologies. Government act as the main actor for the development of technological innovation system. Tanzania government had put in place the exemptions of VAT and duties on solar equipment and other renewable energy incentives to support local manufacturing. To support inventions, the government has put in place the patents regulations in1994 followed by the registration act in 2002 under the Business Registrations and Licensing Agency (BRELA).

For the case of relationships and networks; actor-actor mostly involves collaborations (TAREA-UDSM-VETA) while technology-institutions involves aspects of design for example a directive from Tanzania government to ban deforestation benefited the use of 'clean technology' which ultimately gave rise to the use of more Solar PVs as source of energy. In 2000, actors involved with the solar energy technologies in Tanzania formed a non-profit making and non-governmental organization called Tanzania Solar Energy Association (TASEA) to bring together all the actors in the sector. Later, the association changed to Tanzania Renewable Energy Association (TAREA), to include more members and promote the accessibility and use of renewable energy technologies in Tanzania through the use of advanced knowledge and skills, disseminate information, networking, support the creation of an enabling environment

[32] Energy safari and MegaWatt challenge

for sustainable renewable market, support and encourage best practices, promote local manufacturing of renewable energy products and enterprise development. TAREA is a membership based organization but open to any person, company or institution sharing the same vision as the organization. To date, TAREA has about 60 corporate members and 16 global[33] and local partners.

Table 5 summarize the evoluion of a TIS based on historical events and major interactions in Tanzania. The TIS is still in its early formation stages unlike Japan and Germany that have all three stages since their diffusion had aleady reached its maturity.

	Embryo stage (1990s- to date)
Industrial Organization (IO)	• Emergence of specialized solar solutions firms • Association of actors involved in the solar energy technologies was formed • Emergence small system installers and retailers
Institutional Infrastructure (II)	• University of Dar es Salaam (UDSM) and Dar es Salaam Institute of Technology (DIT) introduced renewable energy technology courses and produced researches • TAREA and VETA introduced the renewable energy curriculum
Technological Infrastructure (TI)	
Government Policy	• The national energy policy for rural electrification (2003) • The electricity net-metering rules (2017)

[33] Global off-grid association, BEST-Dialogue, Enzkreis, Alternative energy Africa, Associazione Microfinanza e Sviluppo Onlus, BSW-Solar, Deutsch-Tansanische Partnerschaft, H.O.T Africa, NSV Netherlands e.t.c.

Major interactions	• Training programs on solar energy installation provided by SolarNow and Solar Energy Technicians and Planners in East and Southern Africa
Critical mass	• Public sector procurement (1990s)
Bridging institutions	• TASEA, TAREA

Table 5. The development of Technological Innovation System (TIS) for solar PV – Tanzania

Source: Author's compilation

4.7 Renewable Energy Policy Analysis

4.7.1 Japan

After the experiences gained from two oil shocks in 1970s, in 1974 Japan initiated the Sunshine Project under the MITI[34] and lasted until 1994.The Sunshine Project, which was a long-term plan for introducing alternative energy[35] technologies, organized implementation of R&D activities in priority areas such as solar, geothermal, coal, and hydrogen energies. The sunshine project was instrumental in shaping the renewable energy paradigms in Japan, during the sunshine project timeline, targets for increasing number of solar PV installations were set-out as well both procedures and guidelines for installations (IEA-PVPS, 2019). In 1978, Japan introduced the "Moonlight Project" objectively in order to stimulate the development and introduction of energy saving technologies (METI, 2016). In 1980, NEDO was established in order to stimulate, introduce and promote public and private development of new alternative energy technologies. In 1989, Research and Development Project for Environmental Technology was established to increase number of researches in the area of clean energy technology developments with the support from the government funding. In

[34] From 2001 the Ministry of Economy, Trade, Industry (METI)

[35] New energies include biomass, solar thermal, and photovoltaic and wind also the innovative use of fossil fuels

1993, the New Sunshine Project was established, which in principle combined the previous three projects with the objective of achieving sustainable growth while tackling environmental challenges such as CO_2 emissions (*Figure 4-29*). The new sunshine project played an important role in creating market penetration of solar PV systems, in the period from 1994-2008, seven incentive programs introduced:

① The monitoring program for PV systems in residential areas was influential in stimulating the growth of solar PV systems. The incentive put forward was the 50% subsidy for installation costs (IEA-PVPS, 2019).

② Program for supporting the funding of infrastructure for new solar PV systems installed (1997)

③ Field test projects for solar PV systems (1998): these field test were given a 50% subsidy for both private and local projects (Izumi, 2007).

④ "Projects for New Energies" (2001): projects that were related to production, as well as commercialization of solar PV systems were profiled for potential funding of up to 50% of installation costs (Izumi, Status of PV Policy and Market in Japan, 2009).

⑤ Subsidy program for local governments: Sanjeeda, Ushio, Ashraful, & driss, (2014) reported that up to 40% of installation costs were subsidized.

⑥ Renewable portfolio standards (RPS): the RPS law came into effect in 2003, as a mean to improve Japan's energy supply as well as environment protection. The RPS obliges private power producers to supply a certain portion (set by the government) of renewable energy in in their total power produce.

⑦ "Action Plan for Dissemination of PV Power Generation" (2008): the plan was to increase solar PV systems installations to 53 GW by 2030 (Sanjeeda, Ushio, Ashraful, & driss, 2014).

In 2012, the Feed-in Tariff (FIT) were introduced replacing the RPS and obliges the electricity power companies to procure electric energy from independent renewable power producers especially on a fixed term contract for fixed price set out by METI. Two years after the introduction of FIT, the installed capacity from renewable sources increased by 32%. *Figure 4-30* summarize the strategies, acts and schemes introduced to develop solar PV industry in Japan.

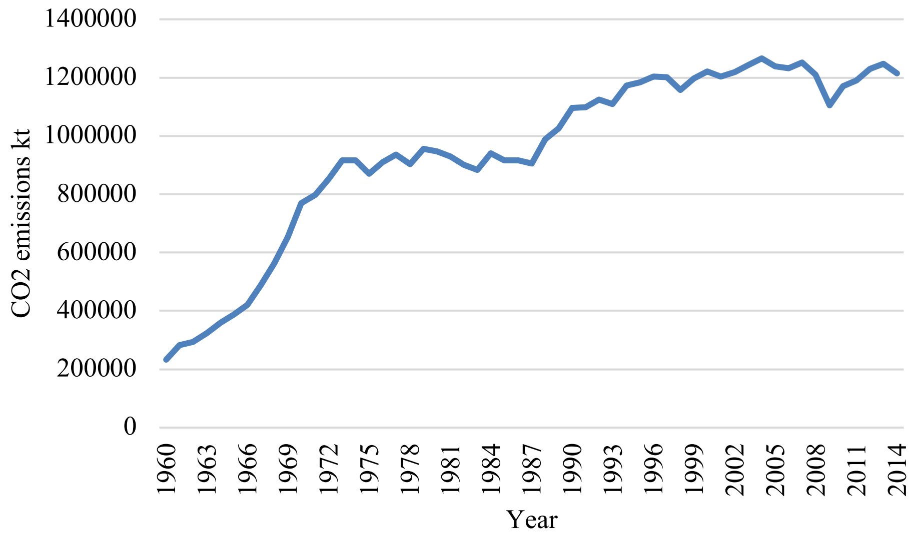


Figure 4-29 Greenhouse gas emissions in japan 1960-2014

Source: (IEA, 2019)

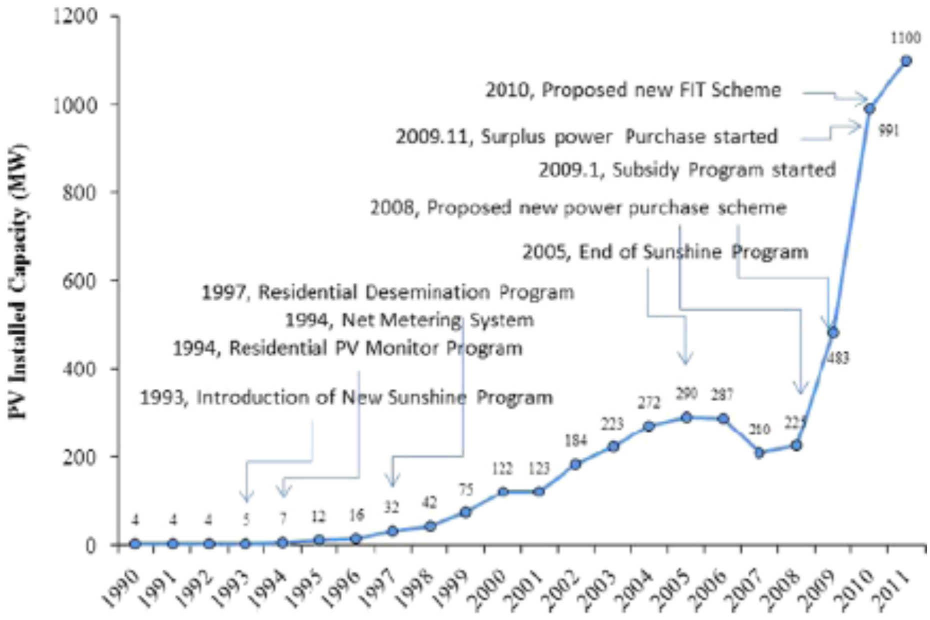


Figure 4-30 Incentive Programs - Japan

Source: (Sanjeeda, Ushio, Ashraful, & driss, 2014)

4.7.2 Germany

The main driving force policy that made Germany the powerhouse in renewable technologies is two policy schemes namely the feed in law termed as "Stromeinspeisungsgesetz (SEG)" in 1991 which mandated the electricity power companies to procure electric energy at small tariffs from independent renewable power producers especially on a fixed term contract for fixed price set out by the government (Sanjeeda, Ushio, Ashraful, & driss, 2014). The SEG played an important role in attracting investments as well as influencing market penetration of solar PV systems, in the period from 1990-1999. The solar PV industry started to gain momentum when the 1000-roofs incentive program was introduced (1991-1995). The incentive put forward under the 1000-roofs was the 70% subsidy for installation costs which independent power producers incurred. As a results, more than the set plan (more than 2000 solar PV systems installed) during the implementation period (IEA-PVPS, 2019). In order to rip the rewards from 1000-roofs incentive program, the government decided to expand into another program, 100,000-roofs in order to strengthen the energy generated from solar PV system and reduce the burden of using coal and oil. All the systems were grid connected and the independent solar PV power producers enjoyed interest-free loans. At the end of 100,000-roofs program, the tariffs were renewed in favor of producers of solar cells/panels (BMWi, 2018). Another important policy strategy that changes the renewable energy paradigm is the renewable energy sources act called “Erneuerbare-Energien-Gesetz (EEG)” which run from 2000 replacing the SEG and amended a considerate number of times to match the industry needs. In the history of solar PV in Germany, under the EEG scheme more investors flooded into investing in the industry to enjoy the benefits. This period between 2008 and 2013, is when Germany became the powerhouse in terms of solar panels production, installed capacity (6 – 36 GW) and jobs creation in the industry. The incentives provided to power producers by SEG and EEG schemes boosted the Germany’s solar PV industry growth. *Figure 4-31* summarizes the strategies, acts and schemes introduced to develop solar PV industry in Japan.

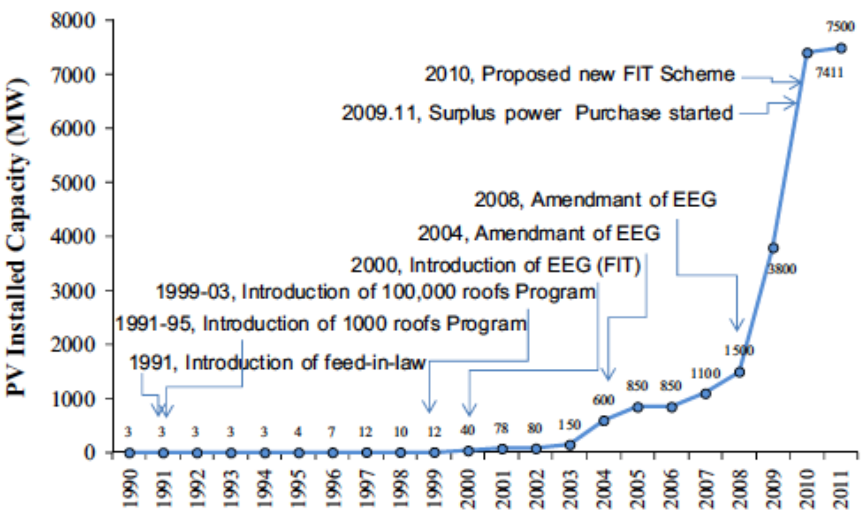


Figure 4-31. Incentive Programs - Germany

Source: (Sanjeeda, Ushio, Ashraful, & driss, 2014)

4.7.3 Tanzania

In April 1992, Tanzania introduced the national energy policy (NEP) objectively for producing adequate and reliable energy supplies for sustainable development. The policy was revised in 2003 to consider the structural changes which have occurred down the years since its introduction (TETI, 2019). The NEP introduction was the driving force of paradigm change in Tanzania for the energy sector because it gave the rise of authorities and acts responsible for renewable energy development such as EWURA[36], REA, REF and Electricity Act 2008[37]. In 2005, the Rural Energy Act[38] was introduced strategically to improve the access to electricity and encourage the development of small power projects from both local and private project developers. REA was mandated to administer the execution of rural electrification projects in Tanzania mainland. In 2008, Electricity Act as introduced with the main objective which states *"… to provide for the facilitation and regulation of generation, transmission, transformation, distribution, supply and use of electric energy for cross-border trade in electricity and the planning and regulation of rural electrification…"* (FAO, 2008).

In 2009 and 2010, the government introduced the standardized power purchase agreement (SPPA) and standard tariff methodology[39] respectively. The SPPAs were introduced to give a legal-binding to private energy developers to connect their generators to the national grid, as well as distributing their excess power to TANESCO (WorldBank, 2011). As a result, 10 SPP agreements (size 0.3-10 MW) were approved

[36] EWURA act 2001 http://extwprlegs1.fao.org/docs/pdf/tan34584.pdf

[37] Electricity Act 2008, 2016 http://www.fao.org/faolex/results/details/en/c/LEX-FAOC085322
[38] Rural Energy Act 2005 http://www.fao.org/faolex/results/details/en/c/LEX-FAOC142174/
[39] Through the concept of avoided costs, the calculated tariff is compared by the cost of alternative options the buyer has.

for introduction by EWURA. Those projects had 40.1 and 22.5 MW (hydro), 15.6 MW (biomass) and 2 MW[40] (solar) projects (Mwenyechanya, 2013).

The new policy, NEP-2015 introduced with the main goal of stimulating and attracting more investments from the private sector as well as local involvement in the energy sector. The NEP-2015 is also focusing on increasing both access to modern energy and the share of renewables in total energy mix (MOE, 2015).

The period from 2003 to 2015 was vital for the energy sector in Tanzania due to the structural changes in terms of policy and regulations summarized in *Table 6*. As a result, the total power installed capacity increased from 891 MW to 1483 MW as well as the connections per households in the period of 2003-2014 (EWURA, 2017).

Laws	The Electricity Act, 2008
	The Rural Energy Act, 2005
	The Energy and Water Utilities Regulatory Authority Act, 2001
Strategy & Plan	Tanzania Development Vision 2025
	National Strategy for Growth and Reduction of Poverty (Mkukuta II), 2005
	The National Energy Policy, 2003
	The Tanzania Five Year Development Plan 2011/12 - 2015/16
	The Tanzania Five Year Development Plan II 2016/17 - 2020/21 (May 2016)
	Strategic Plan 2011/12 - 2015/16
	The National Natural Gas Policy of Tanzania - 2013
	Electricity Supply Industry Reform Strategy and Roadmap, 2014
	Sustainable Energy for All (December 2015)
	National Energy Policy 2015

Table 6. Laws, strategies and policies related to power sector – Tanzania

Source: (JICA, 2017)

[40] Due to tariffs being too low for wind and solar, they were deemed unattractive.

5 CONCLUSION AND POLICY IMPLICATIONS

In this master's thesis, the evolution of solar PV technological systems for three countries Tanzania, Japan and Germany was analyzed using the technological innovation system (TIS). Also the adoption and diffusion of solar PV technology for Japan and Germany was estimated using S-curve models. For the S-curve models, the research has employed three models Gompertz Curve, Logistic Growth Model and Bass Diffusion Model for the main part of the research while other S-curve models such as Sharif-Kabir and Floyd were used to support parts of the analysis.

Recalling the three research objectives raised in this research:

1) To find the contributing factors of solar PV technology diffusion and adoption's success in Japan and Germany
2) To find the diffusion model which explains best the diffusion trajectories (diffusion curves) of solar PV technology in Japan and Germany
3) Does the results of 1 and 2 above gives any help on recommending what set of policies including public and technological are necessary for Tanzania to develop solar PV adoption

5.1 Model Estimation

5.1.1 Findings

The results shows that the logistic model adequately explains the diffusion of solar PV systems in both Japan and German. The results shows that for Japan the total installed solar PV saturation level is 60.28 GW, but the maximum rate of diffusion already occurred in 2015-2016 whereby after 2016 it started to decrease after that. This research estimated that there will be a 58.6 GW total installed solar PV in 2020 in Japan. Also the results shows that, if the TIS for solar PV in Japan remains the same (no revitalization) to not stimulate the diffusion process, the growth rate of installed capacity will continue to decline until 2067 where it will eventually stops. These results shows that Japan is moving in a right direction since they go within the Japan's 2050 plans of having 60 GW of total installed solar PV in the country. The solar PV diffusion in Japan took 7 years to move from 10% to 90% of the 60.28 GW saturation level.

For the case of Germany, results shows that the total installed solar PV saturation level is 42.132 GW, but the maximum rate of diffusion already occurred in 2011-2012 whereby after 2012 it started to decrease after that. This research estimated that there will be a 42.1 GW total installed solar PV in 2020 in Germany which in entails that is at maturity (no growth). Also the results shows that, if the TIS for solar PV in Germany remains the same (no revitalization), the growth rate of installed capacity will continue to decline until 2042 where it will eventually stops. These results shows that Germany's diffusion isn't growing rapidly and more efforts have to be put forward to stimulate the growth of solar PV industry. For Germany to achieve the same level (60.28 GW) Japan is achieving with the current state, it will take 13 years. This shows that the diffusion rate of Japan's solar PV is faster than that of Germany. The results also proved that Japan's diffusion rate is faster when restricting its saturation level to 42.132 GW which shows that it will about 4 years to move from 10% to 90% of the 442.132 GW saturation level while Germany takes 6 years.

The bass model results also showed that, Japan's adoption of solar PV is yet to capture the late majority (34%) who adopt an innovation after average number in a social system had adopted. This means that still a 16% (laggards) of potential adopters of an innovation in the social system are yet to adopt the solar PV technology which tells why the logistic model predicted that Japan is still growing (PV diffusion). For the Germany case, solar PV adoption had already captured by the final adopters (laggards) of an innovation in a social system which suggests that policy interventions should be directed or favor new adopters of PV systems. These findings have expanded the application of diffusion models (Gompertz, Logistic and Bass) to explain diffusion of a technological innovation trajectories in two countries. The estimations for Japan and Germany which have a solar PV industries that already reached the maturity phases are vital for learning purposes for late-comer countries like Tanzania. The diffusion models used in this research could be applicable to Tanzania since they were able to explain those trajectories in Japan and Germany.

5.1.2 Limitations

The case of diffusion of solar technology is a bit different compared to other innovative products. The results of the models estimations have shown that the government can influence the diffusion curve in the case of solar PV technology unlike other consumer products which only words of mouth can lead to a diffusion in the social system. Japan and Germany had steeper diffusion curves due to many government financial support but Japan had a steeper diffusion curve due to the "late comer advantage" or a "time-lag" effect as explained by Dekimpe, Parker, & Sarvary (2000) that the technology will diffuse faster in the country that develop a technology later. Also in this research work we covered only the solar PV technology which is only a small portion of renewable energy. Other renewable energy technolgies such as biomass, wind and hydro were not included in this research work.

5.2 Technological Innovation System (TIS)

5.2.1 Findings

For the TIS utilization, the solar PV TISs for developed economies Japan and Germany as well as an embryotic TIS for Tanzania was mapped out to understand the building blocks and major interactions of the systems. This approach created a room for understanding the technological innovation systems of Tanzania, Japan and Germany in a systemic way, the events occurred that are related to the components of TIS for solar PV diffusion were captured from academic journal articles, websites, reports, and interviewing experts. The analysis showed that, at its embryotic stage Japan's private sector (Tohoku, Sharp, and Mitsubishi) engaged in in-house R&D activities to develop prototype model after the invention of solar cell. These researches create the strong technological infrastructure within the country which in turn creates a strong national innovation system. The institutional infrastructure was also very strong during the early days due to the existence of technological centers by private companies. The establishment of NEDO as a bridging institution in 1980s supported the government bringing together major actors of the systems and making the interactions firm. Both the moonlight and sunshine projects introduced by the government in 1970s were influential in accelerating the growth of the industry. The government interventions such as field test projects for solar PV systems due to the incentives to fund installation cost attracted more investments in the industry which resulted into increased number of installations in the Country. Germany's introduction of feed-in tariffs accelerated investments because the power producers through long term contracts were assured that their energy generated would be purchased unlike the RPS scheme introduced in Japan which obliged power developers to supply a portion of renewable energy to the grid. This explains why Germany overtook Japan in the solar market in 2000s after the "Sunshine Project' ended. The FIT in Germany was a long term project, it helped creating a domestic market. Another notable observation that made Japan and Germany develop their solar PV industry was due to increase in solar cells production the costs of solar PV systems went down (this can be explain due to the effects of learning). For Germany the increase in domestic production was triggered by the amendments of EEG acts which attracted more investors due to favorable tariffs.

Most of the findings shows that Japan and German were able to achieve growth in the solar PV industry due to their strong economic power where we have seen the "government-engineered" diffusion curves for both countries. Most of the initiatives put forward were involved financial support from the government such feed in tariffs. Also in Germany and Japan the costs of electricity are very higher since the public have accepted and can afford. Tanzania as a least developed country, due to its poor economic power should concentrate on the second part of TIS objective which is the "diffusion and use" of a technology rather than investing in order to "generate" or "produce" a technology. The focus should be to adapt foreign technologies through technology transfer. Policy makers in Tanzania should not introduce policies that are addressing only the market failure or directly copied from other countries instead they should introduce policy that address issues related to system failure as well as how to increase the countries technology absorptive performance. The increase in absorptive performance can be achieved by imposing zero tax on the importation of solar PV related systems as well as having long corridor periods for new solar projects to attract more private project developers. Due to poor financial position of local firms, it is difficult to do private researches that are mostly done by firms in Japan and Germany. Public policies that influence more networking among "major actors" of Tanzania solar PV industry will result in having strong relations which might lead to joint researches between universities or firm to firm. The formal or informal interactions facilitate the flow of knowledge which in turn will strengthen the innovative capacity of an industry. The Japan's TIS during the infant stage has seen the formation of many bridging institutions such as METI, MoE, JPEA, and J-PEC. These institutions helped bringing the whole TIS firmly together which in turn made the major interactions between firm-firm, firm-user, firm-research and the government possible. Tanzania should also have policies that facilitate the formation of support institutions that can bring together the whole system which can help the diffusion and adopting foreign technologies possible. These exploration results in Japan and Germany shows that it will be difficult for Tanzania to follow and learn since huge part of it was due to strong financial support which Tanzania cannot do. Also the private entities devoted into R&D activities for decades. This massively boosted the technical knowledge availability which in turn impacted the manufacturing of solar PV related products.

This research showed how strong institutional infrastructure facilitated the growth of solar PV in Japan and Germany, in Tanzania, only two academic institutions offers renewable energy technology courses. The policies that insist the learning institutions such as technical colleges teaching PV system design, installation and maintenance will create more skilled personnel such as engineers and technicians. This will improve the innovative capacity of the major actors in the system as well through networking-policy suggested earlier.

5.3 Further research

This research analyzed the TIS for Tanzania, Japan and Germany by looking into the historical events linked to elements of a TIS. The determinants of PV technology diffusion and success in Germany and Japan were identified and screened to find those which fits Tanzania's realities and propose policy recommendations including public and technological that are necessary for Tanzania to develop its solar PV industry. For future research, it is recommended to also include and implement the system dynamics model to develop a framework by simulating the effect of policy implications over 10, 20 or 50 years for Tanzania or any other least developed country and study the results.

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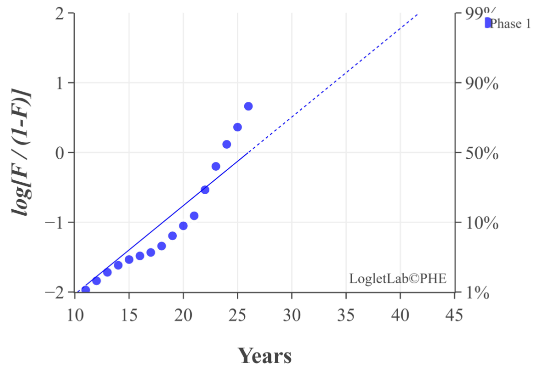
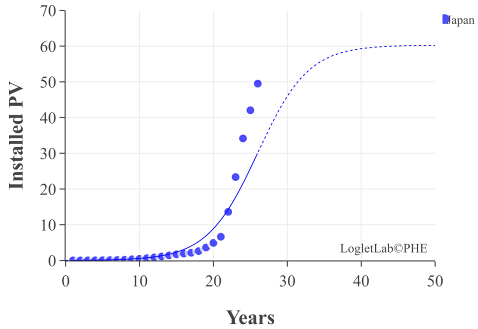
Appendix I: Loglet Lab estimates – Japan

Logistic		d	K	a	tm	r	SSE	RMS	MAD	MAPE	SE	ln[MLE]	AICc	R^2	*p*	1%	10%	50%	90%	99%
Japan	Phase 1 ●	0.000	60.3	15.0	26.0	0.292	892	7.46	4.60	0.361	8.28	-54.9	118	0.914	7.61e-9	10.3	18.1	26.0	33.9	41.7

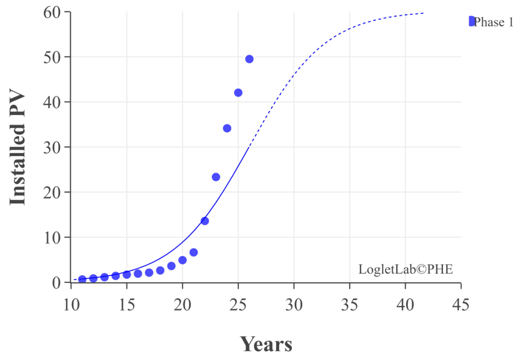
Fisher-Pry



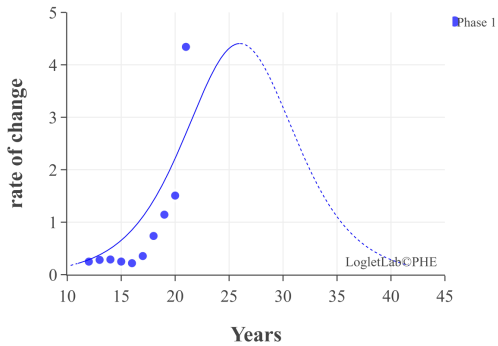
Japan



Component Analysis



Rate



Appendix II: Loglet Lab estimates - Germany

Logistic		d	K	a	tm	r	SSE	RMS	MAD	MAPE	SE	ln[MLE]	AICc	R^2	*p*	1%	10%	50%	90%	99%
Germany	Phase 1 •	0.000	42.1	6.29	14.0	0.699	80.8	2.49	2.03	0.447	2.84	-35.9	80.6	0.991	1.83e-11	7.41	10.7	14.0	17.3	20.6