DIFFUSION OF PHOTOVOLTAIC IN GERMANY: ROLES OF POLICY, SYSTEM SUPPLIERS AND ADOPTERS

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In some countries photovoltaic (PV) technology is at a stage of development at which it can compete with conventional electricity sources. A case in point is Germany where PV market has reached a mature stage. As a manifest of this, the German government has recently reduced the feed-in-tariff, which had been the strongest driver of PV diffusion. This development raises a fundamental question: Why would potential adopters be motivated to adopt PV when feed-in tariff diminishes? The point of departure for the literature on diffusion of PV has been on the effect of subsidies but little attention has paid to adopter motives when the policy support is scaled down. This paper presents an in-depth analysis of the adopter motives for photovoltaic applications. Anchored in an extensive exploratory case study we provide an encompassing explanation of roles of policy, adopters and system suppliers on diffusion of PV.

Keywords: diffusion of innovations, policy, photovoltaic, grid parity.

1. Introduction

Concerns about climate change and the finite nature of fossil fuels have prompted countries to support renewable energy production. The European Union (EU) has set targets of 20% for decarbonisation of the energy sector by 2020 through renewable energy technologies such as photovoltaic (EP, 2009). If all specific boundary conditions are met it is estimated that PV will supply up to 12% of EU electricity demand by 2020 (EPIA, 2012). Germany is in the forefront and has presented a steady growth for a decade as the most developed PV market in the world with 24,678 MW installed capacity. While PV diffusion in Germany is at grid parity, a stage that PV can compete with conventional electricity sources, the market for PV is currently facing some boom and bust cycles related to the recent cuts on feed-in tariff. However, these cuts on German feed-in tariff can be perceived as a testimony that policy makers are convinced that PV technology has matured and hence should be treated like other conventional generators (Fulton et al., 2012). In this regard, understanding of adopter motives for PV gains importance: What are the motivating factors for PV adopters when feed-in tariff diminishes? In order to answer this question, a deeper insight into the diffusion process is needed.

In the literature, the diffusion of PV technology has been studied from different theories and perspectives including fundamental human needs theory (Max-Neef et al., 1992), diffusion of innovations theory (Rogers, 2003), technological innovation systems perspective (Carlsson and Stankiewicz, 1991) and ecological modernization approach (Jänicke, 2008). The studies have revealed the impact of inducement schemes (Jäger, 2006), the importance of politics governing energy transformation (Jacobsson and Lauber, 2006) and the role of regional policy subsidies (Zhang et al, 2011). In addition, the factors triggering adopters for PV have also been widely studied and identified as geography, religion, education, ethnicity and social capital (McEachern and Hanson, 2008); peer-effect (Bollinger and Gillingham, 2012); sunshine duration, housing investment and environmental awareness (Zhang et al, 2011); experience, knowledge and familiarity (Peter et al., 2002); installation costs (Peter et al., 2002; Zhang et al, 2011); and local initiatives (Dewald and Truffer, 2012). However, the link between policy support, adopters' motives and system suppliers still remains to be analyzed, especially in the case of reduction of feed-in-tariff through a policy decision.

The paper addresses the above mentioned limitation based on an extensive and exploratory case study, focusing on the role of adopters and a system provider firm in Southern Germany. The paper is structured as follows. Section 2, develops the theoretical framework. Section 3 motivates the research design and describes how the case study has been conducted. Section 4 describes the case study framework and Section 5 analyses the results of the empirical research and discusses the key impacts on the diffusion process. Finally, Section 6 presents the conclusions, limitations and future lines of research.

2. Theoretical Framework

Variables determining the rate of adoption of PV

The availability of a new technology or innovation does not guarantee its adoption by individuals. To understand this process it is necessary to identify the factors or variables that influence what Rogers (2003) called rate of adoption of an innovation. This rate is conceptualized as the relative speed with which an innovation is adopted by members of a social system. The variables determining the rate of adoption are the perceived attributes of the innovation, the type of innovation decision, the communication channels, the nature of the social system, and the extent of change agents' efforts in diffusing the innovation.

The perceived attributes of an innovation, which can be contingent upon the adopters, explain the 49-87% of the variance on different diffusion rates of different innovations (Rogers, 2003; Tidd, 2009). These attributes are relative advantage, compatibility, complexity, trialability, and observability:

(i) Relative advantage refers the degree to which an innovation is perceived better than the incumbent idea, technology or practice, and is usually expressed as economic profitability.

(ii) Compatibility is the degree to which an innovation is perceived as consistent with the existing values (e.g. sociocultural values and beliefs), past experiences (e.g. previously introduced ideas), and needs of potential adopters.

(iii) Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Normally, there is an inverse relationship between perceived complexity of an innovation and its adoption rate (Völlink et al., 2002).

(iv) Trialability is the degree to which an innovation may be experimented with on a limited basis. Innovations with high trialability often have a higher diffusion rate (Rogers, 2003; Makse and Volden, 2011) although some other studies show an absence of a relationship between trialability and the adoption of innovations (Völlink et al., 2002).

(v) Observability is the degree to which results of an innovation are visible to others. According to Tidd (2009), the rate of adoption of an innovation increases when it is easier to see the benefits of this innovation.

The decisions on adopting innovations can be categorized as optional (where the adopting individual has almost complete responsibility for the decision), collective (where the individual has a say in the decision) and authority (where the adopting individual has no influence in the decision) (Rogers, 2003). Since all these types of decisions centre on individuals, there has been some criticism that they do not give sufficient emphasis on structure, context or collective action (Twining, 2005). However, the diffusion process may involve a mix of all these decision-making types depending on the type of technology, regulations and adopters, as is the case of the renewable energy technologies in different countries (Reardon, 2009; Bodas-Freitas et al., 2010).

Innovation diffusions need communication channels by which messages get from one individual to another. Interpersonal communications and mass media channels (television, internet) are important influences on diffusion rate of innovations in a social system (Majajan et al., 1990; Rogers, 2003). Communication between adopters and the visibility of the adoptions can induce peer-effects, whereby potential adopters decision may be influenced by the previous adopters (Bollinger and Gillingham, 2012). Furthermore, the variables determining the rates of adoption are influenced by a social system, which is a set of interrelated units that are engaged in joint problem solving to accomplish a goal (Rogers, 2003). The members of a social system may be individuals, informal groups, organizations and (or) subsystems. Potential adopters can be influenced for innovation adoptions by the pressure of the social system generated via adopters, public policies, shareholders and organizations (Bass, 1969; frondel et al, 2008). Some recent research have identified the effects of network externalities as significantly important for the diffusion rate of innovations (van den bergh, 2013).

Finally, the diffusion process is boosted by the presence of a change agent, who is an individual who influences potential adopters' decisions in a direction deemed desirable by a change agency. Rogers (2003) identifies the seven roles of change agents as developing a need for change, establishing an information exchange relationship, diagnosing problems, creating an intent to change in the adopter, translating an intent into action, stabilizing adoption (e.g. preventing discontinuance) and achieving a terminal relationship.

Role of actors

According to Carlsson and Stankiewicz (1991), a TIS is defined as "*networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing and utilizing technology*". The TIS approach suggests that the diffusion of a new technology takes place through the interplay between firms, adopters and government bodies, and that this process is greatly influenced by the institutional framework, that is the norms and rules regulating the various segments in society, such as incentives (Jacobsson et al, 2004). As is emphasized in institutional economics (Edquist and Johnson, 1997), institutional framework is important for the specific path a technology takes.

TIS focuses on terms of knowledge and competence flows rather than flows of goods and services (Carlsson and Stankiewicz, 1991). For this reason it is very useful to identify the functions that have been implemented. These functions, which may be dependent to each other and may iterate, directly influence the development, diffusion and use of innovations (Jacobsson et al, 2004; Bergek et al, 2008) and may explain the roles of some actors. According to Bergek et. al (2008), these key functions are: knowledge generation and diffusion, influence on the direction of search among users and suppliers of technology, applications and designs (entrepreneurial experimentation), stimulation and evolution of market, social acceptance and compliance with relevant institutions (legitimation), financial and human capital mobilization, and development of positive externalities (as reduction of uncertainty and the cost of information).

Policy makers

The environmental policy research stream argues that in order to correct inevitable the market failures the role of policy makers is to introduce regulatory measures to foster the adoption of environmental technologies (Horbach, 2008). In this context, much research has gone into the evaluation of the instruments that directly or indirectly affect PV technology diffusion, such as subsidies, feed-in-tariffs or financing (Zhang et al., 2011). In the evolutionary approach, innovation policies are not only seen as a means to correct the market failures (Metcalfe, 1994) but also as mechanisms to foster technological learning which may help to break technological lock-ins as a result of industry standards or high returns to scale (Arthur, 1989; Malerba, 2006, 2009).

According to the TIS perspective, R&D funding for knowledge generation and diffusion in different platforms (demonstration programs, conferences, workshops) and resource mobilization are necessary to solve technological problems and create an innovation with acceptable specifications (Hekkert and Negro, 2009). Policy makers can influence these functions for the purpose of diffusing and utilizing an environmental innovation in search of improvement of solutions for environmental and societal challenges, which in return may increase the economical relative advantage of environmental innovations. That is the case of the early phase of PV diffusion in Germany, where policy makers supported two PV demonstration programmes in 1983 and 1986, and financed PV R&D projects in 15 universities, 41 firms and 17 research institutions from 1990 until 1999 in order to enhance the knowledge base of different agents (manufacturers and system suppliers) and increase the price/performance ratio of PV (Jacobsson et al., 2004; Jacobsson and Lauber, 2006).

The capacity to create expectations for an environmental innovation is essential to foster the diffusion because it gives clear signals to potential adopters and industrial actors about the future attractiveness of the innovation. In this context, policy makers can foster specific regulations in order to guide suppliers and adopters to choose an innovation or a specific design of it. In the period until 2012 in Germany, policy makers gave clear signals about growth potential of PV through the implementation of feed-in-tariffs (Jacobsson and Lauber, 2006; Dewald and Truffer, 2012).

The entrepreneurial experimentation has a prime importance for diffusion of innovations and the development of positive external economies such as entry of new firms and the formation of buyer-seller linkages or networks that provide spill-over effects by the reduction of uncertainty (Jacobsson et al, 2004; Bergek et al, 2008). Policy makers can enforce these functions by funding R&D, designing incentives and creating beliefs in growth potential of an environmental innovation. Watanabe et al (2000) showed that policy initiative in Japan to finance PV to mitigate CO2 emissions resulted in more R&D on PV technology which raised solar cell production and lowered prices.

The articulation of demand from potential adopters and price/performance of the environmental innovations are essential to form a market and to diffuse an innovation. Policy makers can directly influence the ensuing market formation through different instruments such as feed-in-tariffs, subsidies, environmental standards and green labels (Hekkert and Negro, 2009). Beise (2004) demonstrates that the successful diffusion of PV technology in Germany and Japan was based on government subsidy policies. Finally, as a matter of social acceptance, policy makers may organize information and support meetings in order to reduce the complexity of and innovation, ensure legitimacy and hence increase its rate of adoption (Jäger, 2006). In the institutional framework, legitimation is a both prerequisite and a result to foster adoption that policy makers actively involved.

System suppliers

In developed countries, PV system suppliers consist mostly of small and medium intermediary systems integrators and other component suppliers. More recently, the increased demand for grid-connected systems has boosted some component distributors to become full-service system installers that offer and install complete PV packages to adopters. System suppliers' role in the diffusion process has been analyzed mainly through the systemic approach to market formation processes as change agents by communicating with potential adopters, networking with other actors and influencing the innovation itself.

In terms of innovation, system suppliers promote either a package of innovations (elements of technology that are perceived as being interrelated) or each new idea separately. Christensen (1997) explains the importance of compatibility for the role of suppliers in terms of "disruptive innovations" as two aspects. First, the pace of diffusion can be different from the progress offered by technology. Second, a disruptive innovation should fit the needs of current potential adopters. In this context, system suppliers may seek to generate needs among potential adopters, but this must be done carefully, as the campaign may be based only the needs of change agents, rather than those of adopters (Rogers, 2003).

The communication between system suppliers and potential adopters can primarily demonstrate the relative advantage of an innovation as perceived by potential adopters. This is more critical in the cases of environmental innovations such as PV as the relative advantage of environmental innovations can occur at some time in future. As some environmental innovations require a high level of knowledge about operation and financing, it is a need to have an effective communication or a share of a similar background between suppliers and adopters (Dewald and Truffer, 2012). According to Dewald and Truffer (2011) in the diffusion of PV in Germany in 2000s, architects who acts as system suppliers committed to provide information about technology, financing and funding to potential adopters in the small scale (1-10 kWp) PV market and therefore take an important role in the diffusion.

Another advantage that derives from the communication between system suppliers and other actors is the possibility to generate networks that influence the diffusion of innovations. While poor cooperation in networks may fail to enforce diffusion of innovations whereas tight networks cause lock-in effects (Bergek et al, 2008), well established networks take active role in market formation, knowledge generation, legitimation and creating positive external economies. For example, in 1970s the foundation German Society for Solar Energy and the German Solar Energy Industries Association primarily created positive external economies for the later stages of diffusion of PV in Germany (Jacobsson et al, 2004).

Adopters

The role of adopters on the diffusion process has been studied from different perspectives such as the supply-side, in regard to how suppliers can learn from adopters to develop and improve their products (von Hippel, 1986), and the early adopters, in terms of what is the role of these consumers on diffusion processes (Rogers, 2003). For a mature innovation such as PV, the literature focuses on two research areas: demand-side factors, in the sense of which characteristics of adopters influence their decision to accept an innovation, and peer-effects, in terms of how adopters influence each other in a social system.

Different studies have identified that individual characteristics distinguish between early adopters versus late adopters and can influence the perception of all innovation attributes. In this context, the compatibility of an innovation with previously introduced ideas and social norms can either speed up the process or retard its rate of adoption, whereas the desire to gain social status of potential adopters may be one of the reasons to adopt an innovation (Rogers, 2003). In the case of PV systems, the characteristics of adopters that have a higher level of influence on the diffusion of PV systems can be grouped in personality variables, economic status and socio-geographic context. Related to the first group, the consumers perceive a PV system as important in satisfying their needs and have cognitive capacity, experience and knowledge to overcome the complexities of the decision. Other factors that can play a relevant role are the desire to be independent from the electricity supplier, familiarity, religion and education (Peter et al., 2002; Jäger, 2006; McEachern and Hanson, 2008). Related to the other groups, literature identifies that the diffusion of PV systems is accelerated with the increase on sunshine duration and the housing investment of per capita household income (Zhang et al., 2011).

In regard to peer effects, early adopters of an innovation can exchange the information of relative advantage with the potential adopters by expanding the knowledge about the degree to which an innovation is better than existing practice (Rogers, 2003). New adopters are influenced in part by what they see and hear from their peers. Previous adoptions in the same localized area play a role in the decision of a household to adopt (Bollinger and Gillingham, 2012). Adopters of PV systems may act as “advisors” for their peers and neighbours with respect to the installation of a PV system and the administrative procedures involved, which increases the observability and trialability of the innovation and stimulate further diffusion. Peer effects can be fostered if highly motivated adopters formalize social networks to circulate information (Jager, 2006).

Table 1 presents the summary of the theoretical framework.

Table 1. How policy makers, system suppliers and adopters influence the diffusion of PV.

<table>
<tr><th colspan="3">Role of change agents</th><th colspan="2">Impact on adoption rate</th></tr>
<tr><th>Policy makers</th><th>System suppliers</th><th>Adopters</th><th>General</th><th>Specific</th></tr>
<tr><td>Generation and diffusion of knowledge</td><td>Diffusing the knowledge</td><td rowspan="5">Peer effects and positive impact of individual characteristics (e.g. cognitive capacity, economic status, experience, needs)</td><td rowspan="4">Improvement of relative advantage and compatibility</td><td rowspan="4">Feed-in-tariffs, subsidies, environmental standards, green labels, demonstration programmes and funded R&D projects increase the relative advantage and compatibility of PV</td></tr>
<tr><td>Stimulation of market</td><td rowspan="2">Building strong networks and entrepreneurial activities in the market formation</td></tr>
<tr><td>Development of positive externalities</td></tr>
<tr><td>Mobilizing the financial and human capital</td><td>Solving technological problems</td></tr>
<tr><td>Creating expectations</td><td>Search for new solutions (disruptive innovations, dominant design)</td><td>Changes in societal system and communication channels; increase in observability</td><td rowspan="2">PV exhibitions and earlier adopters in the neighbourhood reduce complexity and increase trialability and observability
Politic support and coalitions create regulations, which increase the relative advantage of PV
Green movement and demonstrations change the social norms</td></tr>
<tr><td>Legitimation</td><td>Communication with adopters</td><td>Social influence on policy decisions</td><td>Decrease in complexity; increase in trialability</td></tr>
</table>

3. Research Design

Since the research questions are relatively novel, an exploratory case study research is chosen as a methodology (Yin, 2003). Moreover, as our purpose is to advance theory with the collection of rich qualitative data, the design of a case study is very useful when the researchers try to decode a phenomenological process that evolves over time. We avoided making hypotheses among different variables and we have chosen the observation of empirical evidence and analyzing it in an inductive way.

The research design has an insider-outsider team research approach (Bartunek and Louis, 1996) with one of the researchers spending three months (winter 2012-2013) at a systems supplier located in southern Germany, Hartmann Energietechnik GmbH. The main data source was collected through direct interviews with adopters and employees of the firm. All interviews were semi-structured with open-ended questions using an interview guide.

The purpose of interviewing both adopters (demand-side) and employees in the firm (supply-side) was to get a deeper understanding of the context of diffusion of PV. The respondents from the demand-side included the adopters that have bought PV during 2012, the year that the German feed-in-tariff was rapidly cut. In total nine PV adopters were interviewed of a total of 34 PV adopters that installed PV from the firm in 2012. All the respondents are located in Tuebingen, mainly in the area of Rottenburg am Neckar. The respondents from supply-side included nine technical and marketing staff of the supplier firm who interacts with adopters of both PV and other alternative renewable technologies provided by the firm (solar thermal energy and biomass).

The data was triangulated with other data from additional interviews with the directors of four partner firms of the regional PV association (Solar Partner e.V), observations made in the firm, meeting notes from the 2-day-long annual meeting of Solar Partner e.V, and communications between adopters and the firm. Finally, all these information was completed with secondary information collected from different internal reporting of the firm, newspaper articles and website news. The field study lasted seven months, from December 2012 to June 2013.

4. The Case Study Framework

The case study, focussed into the context of PV diffusion in Germany in 2012, is characterised by the following facts:

(i) The technological development of PV cells was deemed to have reached a mature stage and thus was assumed to compete with conventional electricity sources.

(ii) The policy decision to cut feed-in tariff posed a profound challenge for the future direction of the industry.

Year 2012 - Reaching the grid parity

The technological development regarding to the efficiency of different type of solar cells is constantly improving (NREL, 2012). A typical commercial solar cell has a ratio of electric generation to the sunlight striking the cell around 18%. Moreover, from an economic perspective, PV production cost has been continuously decreased. As a result of these developments, the relative advantage of PV systems has been scaled up and particularly in Germany; PV has already increased to a level, grid parity, where it could compete with other conventional electricity sources.

The relative advantage of PV systems is commonly explained in terms of levelized cost of electricity (LCOE), €/kWh, a calculation of cost of electricity generation based on different variables as the initial capital, solar radiation, costs of continuous operation, service life time and costs of maintenance. The comparison of the LCOE of a PV system and the average electricity price in Germany shows that since the beginning of 2012 the electricity consumed from a PV system was cheaper than buying the electricity from the grid (figure 1). By the end of 2012, LCOE of a typical PV system in Germany was between 0.12 and 0.21 €/kWh, whereas the electricity price from the grid was about 0.26 €/kWh. This fact represents a fast improvement for PV in compare to May 2010, by when LCOE of a typical PV system in Germany was between 0.20 and 0.34 €/kWh, while the electricity prices was about 0.23€/kWh. As a consequence of this rapid decrease on the PV LCOE and the increasing of electricity prices in Germany, the government has been reducing the feed-in-tariff gradually since 2010, but drastically in 2012.

The German feed-in tariff scheme is widely accepted as the strongest driver for diffusion of PV since 2000 (Dewald and Truffer, 2011). This ensures that PV adopters paid with fixed feed-in tariffs for the next 20 years from the time they are connected to the electricity grid. However, the feed-in tariff for PV has decreased more rapidly than that for any other renewable energy technologies (Wirth, 2013). As a consequence, the adoption rate experienced some boom and bust cycles as presented in figure 2.

There is a clear correlation between the rate of the feed-in-tariff and the number of PV installations per month. The number of installations has notably increased just before the reductions of the feed-in-tariff as seen in the months of December 2009, July 2010, December 2010 or July 2011. By contrast, since April 2012 the feed-in-tariff diminishes gradually month per month which prevents boom and bust cycles but discloses seasonal effects.

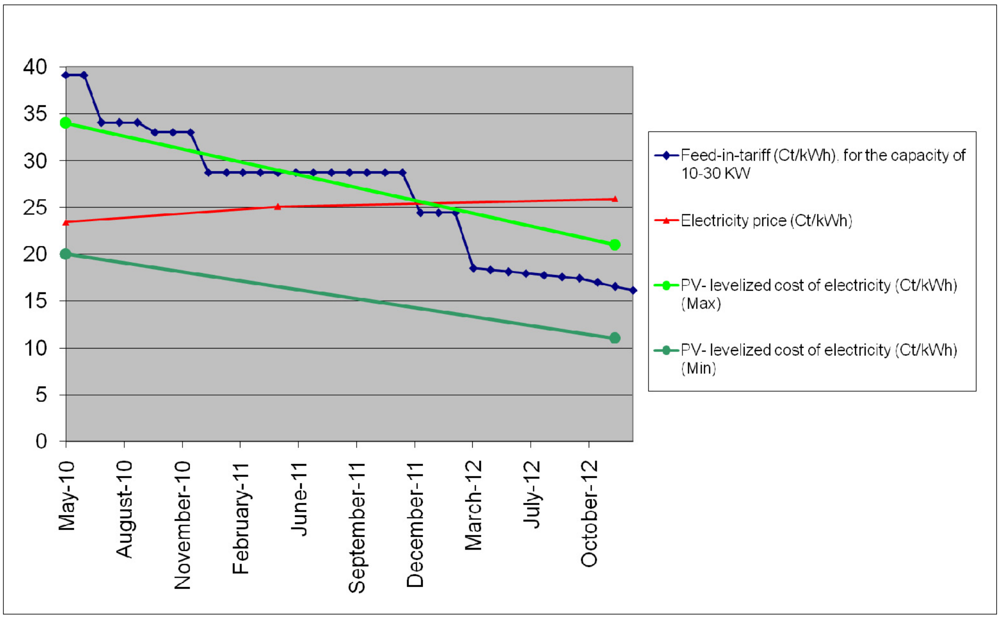

Figure 1. PV electricity generation costs vs. electricity price from the grid.

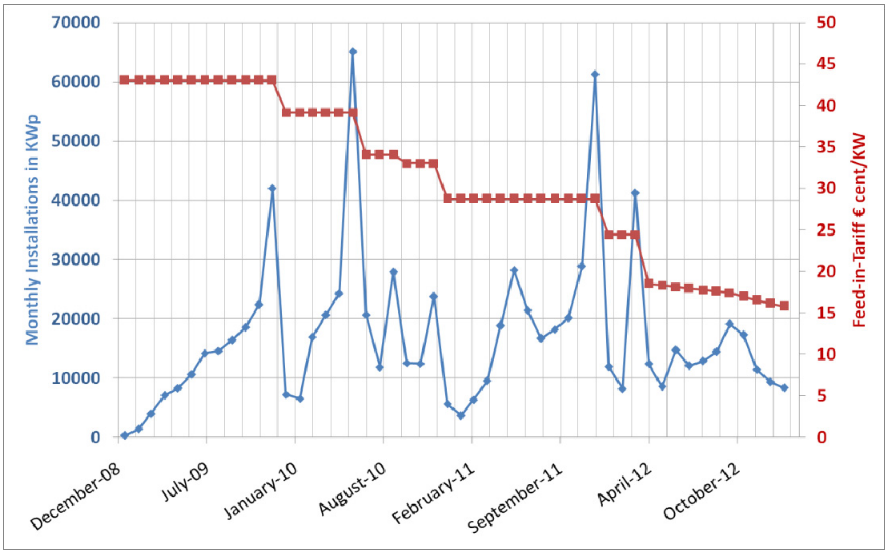

Figure 2. PV electricity generation costs vs. electricity price from the grid.

Hartmann Energitechnik

Hartmann Energitechnik GmbH (HET) was founded in 1995 in the village of Oberndorf in Rottenburg am Neckar (a town with 43000 inhabitants) by a local entrepreneur, Thomas Hartmann. HET is located in so called “Solar-Center” and offers PV, solar thermal and biomass boilers for the citizens in the neighborhood in partnership with two regional associations: Solar-Partner e.V. and Sonnenhaus-Institut e.V. In 2012, HET had 24 employees and its sales volume was around 3 million Euros. In the PV branch, the main activities of HET are focused on promotion, consulting, conceptual designing, assembling and installation. It offers a wide range of solutions depending on the needs and preferences of potential PV adopters: various montage systems (e.g. pitched roof, flat-roof mounting system, building-integrated, façade) and alternative concepts (e.g. carports, transparent modules, energy storage and self-consumption). In 2012, the PV solutions offered by HET was adopted not only in Rottenburg am Neckar (30% of adoptions) but also in other neighborhoods in a radius of up to 50 km. HET shared around an average of 10% PV market in the neighbor towns in respect to installation numbers.

Since the introduction of feed-in-tariff for PV in Germany in 2000 by the federal government, HET focused on the manufacture and installation of PV systems. HET installed many PV systems in the neighborhood and triggered interactive discussions with the interested house owners. In the beginning of 2000s, the efforts of HET took a lot of attention from the government as well. In 2001 HET was visited by the Mayor of Rottenburg am Neckar, and in 2002 by a minister of the regional government in order to have solar-walks and get informed about solar systems diffusion in the region. In 2004, HET co-founded the association of Sonnenhaus-Institut e.V., an institution for architects, engineers and managers of the solar industry with the goal of sustainable development and distribution of construction and heating techniques for largely solar-heated buildings. In 2006, as a pilot project of the association, Solar-Center was build with a capacity of 60 kWp PV systems on the roof and 150 square meters of solar thermal on the façade that provide 80% of energy by itself.

HET pays special attention to its relations with potential clients and other system suppliers. Cooperation with suppliers is based on networking and knowledge creation activities through the associations of Solar Partner e.V and Solar-Haus Institut e.V. On the one hand, Solar-Partner e.V., with its 200 co-workers, stands for partnership in purchasing, marketing, public relations, training, know-how exchange and technical improvements. The four member companies, which are located in radius of 200 km, are in close contact with each other through common reference materials directly from local manufacturers. On the other hand, Solar-Haus Institut e.V., with its 167 national wide members, arises as an independent and open information platform of expertise to planners and companies for experience and information exchange. It conducts joints projects with many research institutions such as the Fraunhofer Institute for Solar Energy Systems (Freiburg) and the Institute for Thermodynamics and Thermal Engineering (ITW) of University of Stuttgart.

HET relationship with potential adopters are based on the facilities in Solar-Center and monthly “Solar-walks”. Solar-Center is a transparent place where the potential adopters can see any part of the facilities (assembly hall, design unit, and exhibition part) and get experienced about PV solutions. It also serves as meeting place for seminars, construction courses, open-doors day and guided tours about PV, solar thermal and biomass. “Solar-walks” are regular 3-4 hours exhibition tours in the village of Oberndorf, where PV systems that HET installed are explained and discussed. Anyone who is interested can join to these solar-walks and get to know about different PV concepts on the field. The visitors of these solar-walks have not been only limited to the region, there have been many amateur and professionals guests from all over the world such as USA and Japan.

5. Discussion

To discuss the variables determining the rate of PV adoption in 2012, we separate the analysis into three parts as the role of policy makers, system supplier and adopters.

Policy makers

The functions of the TIS perspective are key pre-requisites for explaining the roles of policy makers for the period before PV reached grid parity. In 2012, at the start of PV grid parity, the role of policy makers became more indirect than previous years. There is clear evidence in the case study that policy makers, together with other actors, create a negative expectation about the electricity prices in future and this legitimation motivates house holders to adopt PV. Policy makers determine the rules for calculating EEG levy (the portion of the electricity price that must be paid by the end user to support renewable energy) and other kinds of taxes, which partly sets the electricity price in the market (Wirth, 2013). In the case study, respondents from both supply and adoption side reports the importance of the increasing electricity prices on the adoption decision:

(i) "The people in their 30s are afraid of how to reduce the cost of the electricity costs…" (G.W., Director of a partner firm in HET network, 07.12.2012).

(ii) "Electricity will be more expensive in the coming years… then I said I just do not want to pay much. I would also have advantages (of it)." (F.Z., PV adopter, 24.01.2013).

(iii) "We wanted to invest in PV because of the economical and global situation that we don't know which way we are going." (P.M., PV Adopter, 21.12.2012).

It deserves a special attention the fact that policy makers can influence on which conceptual design may become the dominant design (Utterback, 1994) or disruptive innovation (Christensen, 1997) of PV systems. The respondents frequently discussed about the self-consumption, a concept based on an additional battery system and self usage of PV electricity. This depends on relative advantage, which is indirectly shaped by decreasing feed-in-tariff and increasing electricity prices:

(i) "I believe that the PV (diffusion) will grow even though the policy support and feed-in-tariff decrease (...). Now we have feed-in-tariff less than what we pay for electricity, it is 10 cents less ... It means that the self-power consumption is becoming increasingly important when people are more and more afraid and think more and more on self-power consumption..." (G.W., Director of a partner firm in HET network, 07.12.2012).

Interestingly, corresponding to this tendency, a program to promote small scale storage batteries for photovoltaic systems started to be subsidized for those who have been installed after 31st December 2012. Considering the functions of TIS perspective, we could argue that this new subsidy scheme for solar batteries (direction of search) may develop positive externalities by entry of new firms and sub-market creation. In the field study, we observed that Solar Partner e.V. association collaborated with a new solar battery firm in order to discuss how to integrate PV systems with battery systems. However, other functional PV concepts stay still as a part of niches markets. An example of these are building-integrated photovoltaic and façade systems:

(i) *"Building-integrated photovoltaic is very expensive, very expensive! You can see it only in France, because building-integrated PV is there (in France) subsidized. Building-integrated PV architecture is beautiful, no question, much nicer than seal down there, which is set up so artificially. It is just a question of whether the customer can afford it or not." (G.W., Director of a partner firm in HET network, 07.12.2012).*

As a matter of social acceptance about PV systems, observations in the field study indicate that policy discussions on renewable energy system are a hot topic in mass media channels. These discussions reach to even the young generations with different communication channels. One of the respondent´s child reported that renewable energy systems is an important topic that they comment and discuss in primary schools. Theoretically this relates to two of the perceived attributes of the innovation: compatibility and complexity. As renewable energy systems are designated as the key tool for the future of German electricity supply by policy makers, the on-going discussions on PV systems decreases PV´s complexity and makes them compatible with socio-cultural values.

System suppliers

A mix of all decision types were reported in the field study: "optional decision" where the place belongs to adopter; "collective decision" where adopters stay in a common place (e.g. apartment) and has a say in the final decision; and "authority decision" where the adopter is temporarily occupying the place that PV is installed (e.g. renter). It was noticed that the adoption decision is unlikely to be positive if more than one individual have a say in the decision as described in collective decision types. Regardless of type of decision, system suppliers, however, can offer alternative PV system solutions based on different needs and this may change the final decision. E.g. if a potential adopter is building a new house, system supplier can offer the building-integrated PV systems in order to reduce the amount that would spend for conventional building materials, as building integrated PV system is used in parts building envelope directly (increase on relative advantage). Here, offering the best solution that fits to needs of potential adopter (decreasing complexity and increasing compatibility) is not only a typical role of an experienced system supplier but also a key to foster adoption rate.

Respondents emphasized that decision to adopt PV systems require some level of knowledge about technology, operation and funding. It is reported that it is often essential to have an effective communication and a share of a similar background between suppliers and adopters, which has been also stressed before in literature by Dewald and Truffer (2011, 2012). This is related to variables determining adoption rate given to fact that such an effective communication minimizes the complexity via change agent efforts such as a system supplier.

Another finding is that system suppliers are also important in creating peer-effects. The case study reveals that system supplier firms may also influence the adoption rate with neighbourhood effect on potential adopters due to image motivation. HET has PV systems on roof itself, visible from the neighbourhood, and offer to open the doors of its solar centre anyone interested with its periodic solar-walks and open-door days. These interactions improve the trialibility of PV as perceived by potential adopters.

(i) *"(...) we are a local company and we have many relative reference systems here in the neighborhood, and yes I think that is well known. Plus, the combination of the brand Thomas Hartmann has built, solar center, solar walk, that talking to feelings, not just to purely technical side, also showing off the products. There is a building here. That is always the most important, if one builds a place where people can see. Not every customer care about the purely technical data, but they want to experience." (S.L., Solar Thermal Expert by HET, 31.01.2013).*

(ii) *"(Why have you chosen HET?) Because I work nearby and I always have contact with HET." (H.J.R., PV adopter, 29.01.2013).*

In particular, respondents and observations confirmed earlier research results regarding to the role of established networks on the market formation, knowledge generation, legitimation, and creating positive external economies. Specifically, the networks of HET are observed to be prominent to contribute on knowledge diffusion about PV systems.

Adopters

Adopters are not only decision makers but also change agents who influence the adoption rate in a social system in different ways. According to the research framework, we separate the role of adopters on diffusion rate in two parts. First, we analyse the main adopter motives for PV systems; and secondly, we focus on how adopters influence each other in terms of peer-effects.

In line with the literature, the desire to be independent from electricity suppliers has increased recently because of increasing electricity prices. In addition, respondents indicated that PV is often perceived as an "investment" alternative to other traditional investment option. This has not been addressed in the literature before, although it is related to the relative advantage of PV and the transitions in social systems:

(i) *"In the back of my head, I would prefer to be completely self-sufficient and if we could (in our current new house) make everything for ourselves and would not need public electricity." (C.W., PV adopter, 29.01.2013).*

(ii) *"(My motives were) on the one side to make an investment and on the other side to be environmental friendly, i.e. how I can protect my environment. Then I thought, yes, I make PV system on it (the roof)." (F.E., PV adopter, 01.02.2013).*

Adopters frequently recognized impact of the peers upon the adoption rate of PV at the local, regional and as well as global levels. At the local level, in line with the literature on peer effects (Bollinger and Gillingham, 2012), the case study confirms that there is positive influence of previously installed PV systems located nearby on the adoption rate of PV. Peer effects in neighborhoods decrease complexity for potential adopters and increase the compatibility with the social norms:

(i) *"Several reasons available (for adopting PV). One reason is that we are living in Tubingen… There are a lot of buildings which have PV on the roof…" (P.M., PV adopter, 21.12.2012).*

(ii) *"Since solar systems were actually built more and more, I have been thinking about building a house and equip it with PV, (since) 10 years." (H.R., PV adopter, 23.01.2013).*

Corresponding to the regional and global level, respondents emphasized that there was an indirect impact of Fukushima disaster in Japan (2011), followed by the protests against nuclear power in Germany (2011-2012) and the Stuttgart 21 Project (an urban development project which was protested based on economical and environmental concerns on 2009-2011). All these kind of protests had an impact on policy makers decision (on May 2011) to shut all nuclear reactors by 2022 and the adoption of the new Act on Granting Priority to Renewable energy source (EEG 2012 on June 2011). This is an interesting illustration that adopters, as change agents, can influence the policy decision and therefore the functions of TIS (e.g. legitimation), which may influence the adoption rate of a technology.

6. Conclusions

The paper aims to overcome the limitation related to extant research on PV diffusion when there is a reduction of feed-in-tariff through a policy decision. To achieve this aim, the paper develops a theoretical framework integrating contributions from different streams of research: diffusion of innovations theory and technological innovation systems approach. This alternative way to explore the deployment process has allowed to identify several aspects on the adoption of PV systems:

(i) Policy makers have a direct influence on the relative economic advantage of PV. However, the role of policy makers changes when the technology reaches maturity both from the technical and economic perspective (grid parity in our case). Before it, feed-in tariff is the strongest instrument and different functions explain the role of policy makers. Nevertheless, when this stage is consolidated, this role has a more indirect impact on these functions, while maintaining its level of legitimacy. Creating a negative expectation and having an influence about electricity prices are illustrations of how policy makers indirectly affect the diffusion of PV in a mature stage.

(ii) System suppliers offer alternative solutions seeking to reduce the complexity of the systems and increase the compatibility with adopter needs. One of the alternative solutions could turn into a dominant design, especially if it is explicitly supported by policy measures. Given the fact that PV systems require some level of knowledge about technology and its operation, high level of communication between system suppliers and adopters is a key factor to minimize the complexity and to facilitate the decision taken by the adopter. In addition, system suppliers create not only positive externalities through strong networks with suppliers and but also peer-effects on adopters.

(iii) The role of adopters is twofold. On one hand, their decisions are oriented within the social system to which they belong and, in particular, geared towards having a robust investment, getting a better natural environment and independence from electricity supplier as a result of the increase in electricity prices over the medium to long term. On the other hand, they have influence on potential adopters through the so-called peer effect. This effect, locally, has two direct implications: decreasing the complexity for potential adopters to buy the technology and increasing the compatibility with the social norms. At regional and global levels, adopters have an indirect impact on PV diffusion as a result of environmental movements which can influence the decisions of policy makers.

Finally, the research is explorative and presents some limitations. The most relevant is that it is based on a single case study and therefore any generalization of the results should be carefully considered. In particular, factors related with individual characteristics, economic status and socio-geographic context of adopters should be analyzed in the framework of future research.

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