Photovoltaic Cells: A Case Study of Adoption Theory Across Nations

by

Jeffrey Galpin[1], SuHyeon Lee[2], Erik Roach[3], Zac Slovarp[4], and Harm-Jan Steenhuis[5]
Eastern Washington University, Department of Management
668 N. Riverpoint Blvd. Suite A, Spokane, WA 99202, USA
E-mail: [1]jeffrey.galpin@eagles.ewu.edu, [2]schlee5399@hotmail.com,
[3]erikroach@live.com, [4]zslovarp@hotmail.com, [5]hsteenhuis@ewu.edu

IJMBE International Journal of Management, Business, and Economics

Photovoltaic Cells: A Case Study of Adoption Theory Across Nations

by

Jeffrey Galpin[1], SuHyeon Lee[2], Erik Roach[3], Zac Slovarp[4], and Harm-Jan Steenhuis[5]
Eastern Washington University, Department of Management
668 N. Riverpoint Blvd. Suite A, Spokane, WA 99202, USA
E-mail: [1]jeffrey.galpin@eagles.ewu.edu, [2]schlee5399@hotmail.com,
[3]erikroach@live.com, [4]zslovarp@hotmail.com, [5]hsteenhuis@ewu.edu

Abstract

This study explores the nature and many intricacies of the burgeoning solar power industry. We will be examining in particular, the changing market for photovoltaic cells. The purpose of our research is to gain insight into the adoption decisions faced by firms adopting a technologically advanced product. Research into renewable energy sources, more specifically solar power, is of vital importance due to the fact that fossil fuels will eventually be depleted. Photovoltaic cells are experiencing rapidly diminishing costs with grid parity expected to occur in the near future. The five leading countries in terms of cumulative installed megawatts are Germany, Italy, Japan, Spain, and the United States. We examined the presence of factors of adoption, derived from the extensive literature on the topic, in the market of firms that have been successful in adopting solar power. Methods used include the analysis of secondary qualitative data as well as the analysis of specific indicators related to these factors of adoption.

Keywords: Solar Power, Solar Industry, Renewable, Photovoltaic Cell, PV Cell, Adoption, Adoption Theory, Diffusion, Diffusion Theory, Factors of Adoption

1. Introduction

The marketplace for solar power is rapidly changing due to both the swift pace of technological advances, as well as the changing nature of the market itself. Growth is occurring quickly as each country attempts to increase their supply of renewable resources. Figure 1 shows the relative growth of the power supplied by photovoltaic power in two different countries, the United States, and Italy.

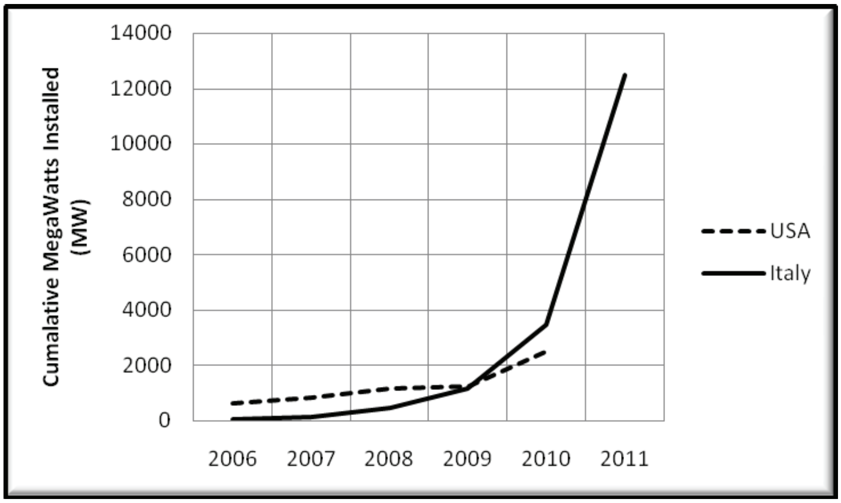

Figure 1 The Growth of Solar Photovoltaic Energy

Figure 1 illustrates varying adoption rates across national boundaries. The purpose of this paper is to gain insight into these varying adoption rates and patterns across nations. We will use solar photovoltaic panels as a case study through which to examine adoption decisions.

Solar energy

Solar energy production is an energy source that either directly or indirectly uses the sun for energy. Solar power has many advantages; chief among them being that it is a renewable resource and that it also has lower carbon dioxide emissions than other forms of energy production (Marques and Fuinhas, 2012). There are several different types of solar power one of which is called photovoltaic panels, hereafter referred to as PV, PV cells, or PV panels. PV cells convert sunlight directly into energy using the photoelectric effect (Beck, 2006). One major advantage of PV cells is that they are highly modular. In other words, you can put a group of them on the roof of your house, or you can build a massive large scale installation capable of powering entire cities (Beck, 2006).
The major goal of solar power development is to reach the point where it can compete with conventional energy sources without government assistance. This point is called grid parity. The irony in this goal is that when solar power achieves grid parity, it will be competing against energy forms that receive government assistance (Keating, 2012). This has led to many industry leaders in the solar community to call for the repeal of all subsidies related to power generation (Keating, 2012).

History

Photovoltaic power was first discovered in 1839 by Edmund Becquerel, a teenage French physicist. He discovered that certain materials could produce small electric current whenever they were exposed to light. In the 1860s, Willoughby Smith discovered that electricity flows well when selenium was exposed to light. It was later discovered that solar energy creates a flow of electric power in selenium. Charles Fritts made the first Photovoltaic Cell (PV) in the early 1880s. He placed a layer of selenium on a metal plate, coated it with a gold leaf, and placed it under sunlight. The cell made more energy but not enough for use. By the mid-1880s, PV cells were being used for power in rural areas where electric cables were too expensive. Today, many corporations have large solar power stations that generate electricity using PV systems. These power systems cover large areas and are often referred to as solar farms (Goetzberger and Hoffmann, 2005).

Challenges

Photovoltaic cells in relation to solar power have the potential to provide positive impacts on the economy and environment. However, there are a number of issues with the technology that could hinder its effectiveness. The Maximum Power Point, or MPP, is of vital importance to PV cells. It is imperative that solar panel PV systems collect the maximum or peak amount of energy available at every single moment in the energy collection process. Efficiency is measured by the solar panel inverter's ability to operate at the MPP constantly.

The majority of issues with current PV systems are with "power losses" which are due to problems like module mismatching and partial shading.

Module mismatching: PV Cells are manufactured with relatively large power tolerances in terms of output capability and they are sorted during manufacturing into bins and categories with cells in the same power output category. By categorizing the PV cells together based on power output capabilities, panels are produced with smaller tolerance variances for output power. Solar panel modules are typically connected in a series, with each providing slightly different MPP currents. By connecting the modules in a series with the offset MPP currents, the optimal MPP currents can never be drawn from the panel series. There is an inverter in the panel series system that selects the specific current with the highest average peak of power production, which is usually less than the sum of the power production peaks of all the modules in the panel series. The difference between the peak average used and that of the sum of the modules as a whole is referred to as mismatch loss, which can be as high as 5% in residential and commercial solar panel series. (Solar Edge Technologies, 2012).

Partial shading: partial shading of the PV cells is another common issue that occurs and is one of the most difficult to prevent. MPP variations can be caused by a number of factors, such as variations in temperature and partial shading, but losses in MPP occur primarily from two factors: an inability to locate the array's peak power point and an inability to track changes in the peak power point at the correct speed. In some cases, shading can cause an array to exhibit multiple peak power points, and in most of the cases the shift between these points can happen quite rapidly. Losses occur due to the array's ability to change with and track the changes in the peak power points (Solar Edge Technologies). The partial shading of the cells is caused by anything that produces a shadow over the cells, such as chimneys, clouds, trees, snow, and shade from the building itself. The shade causes different levels of illumination to the solar panel PV cells, reducing the total output of the panels. The output of all shaded cells is lowered due to the amount of reduced light intensity falling on it caused by the previously mentioned light blocking obstacles. However, the cells covered by shade are not the only cells affected. Because they are connected to other cells on the panel via electrical circuits, the potential output of those connected cells could be lessened as well. In a number of solar panel designs, PV cell modules are connected and grouped into "strings" and if just one module in the string is shaded it negatively affects the output of the entire string, which decreases the output of the module as a whole. Even having one cell in a module completely covered by shade can reduce the overall output from 40% to 95%. In some cases, more than one module can become entirely shaded which can cause the array to be below its operating point, or under its "voltage situation". Overall, the loss of power can be significantly greater than what is lost by the shaded cells due to their effect on the rest of the PV cell string and module, which may include non-shaded cells that will not operate due to their connection to the shaded cells. Restricting the size of the array can be seen as an alternative to avoid all shading, however, this cuts down on the arrays total capacity for output. In cases such as residential panels, partial shading would be more acceptable and the lesser of two evils with shading being inevitable, causing potential annual power losses between 5% and 10%. (Solar Edge Technologies, 2012).

Other issues with PV Cells are rooted in safety features, causing risk to those working on the machine, as well as system design limitations (Solar Edge Technologies, 2012). Safety is one of the largest concerns with PV cells. A number of standards have been put in place to improve safety but there are still a couple of major issues associated with the PV cell solar panels. First, electrocution is a major concern when operating the arrays. For example, there is a connection between two PV modules that, when the modules are taking in sunlight, produces a voltage high enough to kill anyone who touches it. Another major issue is the danger that PV cell arrays provide to firemen who may be putting out a fire in a house in which the system is installed. The first step firemen take in putting out a fire is to cut the power to the building so that they may spray water and cut holes in walls and roofs. By cutting the power they believe the power source of the building no longer has the ability to harm them, however, in a building with PV cell arrays installed cutting the power to the building doesn't remove the high voltages put off by the string ends of the array, meaning that that firemen could potentially be electrocuted while attempting to eradicate a fire (Solar Edge Technologies, 2012).

Another current issue about PV cells is related to the cost of operation. Compared to other forms of energy, the cost of solar cells is significantly higher. However, as with any new technology, as it improves the cost is expected to go down. For instance, the use of chemicals that are cheaper than selenium could dramatically reduce costs (Goetzberger and Hoffmann, 2005).

2. Literature Review

There is a wide body of literature that examines how firms make adoption decisions, that is, how companies decide whether or not to use a new technology. Hoppe (2002) presents a framework through which to view the different models that have been presented over the years. It is depicted in Table 1. The columns reflect the certainty that the new technology being considered is both profitably and that it can be successfully adopted. The rows reflect the nature of the market place. In the first column, there are no strategic interactions between firms whereas in the second column, firms compete.

Table 1 Classification of Models of Adoption based on Hoppe (2002)

Interaction in the product market	Arrival and value of new technology	
	Certain	Uncertain
Non-strategic	Stoneman and Ireland (1983) Farrel and Saloner (1985) Ireland and Stoneman (1986) Jovanovic and Lach (1989) Chari and Hopenhayn (1991) Götz (1999)	Jensen (1982,1988a, 1988b) Baker and Lippman (1984) Bhattacharya, et al. (1986) McCardle (1985) Chatterjee and Eliashberg (1990) Mariotti (1992) Weiss (1994) Kapur (1995) Farzin et al. (1998) Vettas (1998)

		Doraszelski (2000a, 2000b) Thijssen et al. (2000) Alvarez and Stenbacka (2001)
Strategic	Reinganum (1981a, 1981b) Fudenberg and Tirole (1985) Hendricks (1992) Riordam (1992) Riordan and Salant (1994) Dutta et al. (1995) Hoppe and Lehmann-Grube (2001a, 2001b)	Jensen (1992a) Lippman and Mamer (1993) Stenbacka and Tombak (1994) Bergemann and Välimäki (1997) Boyer et al. (1998) Décamps and Mariotti (1999) Götz (2000) Hoppe (2000a, 2000b) Huisman and Kort (2000)

Hoppe's (2002) model does an excellent job of presenting the different theoretical constructs regarding technology adoption in a thoughtful and effective way. However, it is rarely the case that one industry falls neatly into one of these categories. Therefore, we will be considering a combination of factors drawn from these models that we will use to examine the international diffusion of solar PV cells.

Initially eight factors were taken from the preceding theories. These eight factors have been shown to affect the adoption decision that a firm will make by varying degrees. Table 2 gives a brief explanation of each factor as well as how they can affect the adoption decision.

The eight factors were reduced to four. Two of the factors, uncertainty that adoption is possible and anticipation of new improvements were judged to be product specific. Therefore they would not vary across countries. Two other factors, i.e. 'information spillover effects' and 'cost of information collection' were considered to be related to 'size of the firm'. Thus, in the interest of not over-representing these variables we made the decision to drop them from further analysis. This led to the conceptual model in figure 2. Decision makers take into consideration the market conditions and the adoption factors to reach a decision on whether to adopt or not.

Table 2 Factors of Adoption

Factor	Influence on adoption
Size of the Firm	The size of the firm affects the level of risk aversion present, and the amount of capital a firm is willing to invest in new technology. (Karshenas and Stoneman, 1995)
Presence of Network Externalities	The effect that a good or service has on the value of that product to other people who are not the user. The presence of network externalities often hampers adoption decisions, but can help them. For example, high levels of pollution could help entice some firms to adopt clean energy sources. (Farrell and Saloner, 1985)
Number of Competitors	The number of competitors affects the type of interaction in the market. The type of competition can also lead to there being an inherent 1^{st} or 2^{nd} mover advantage in adopting new technology. (Reinganum, 1981)
Uncertainty that Adoption is Profitable	A higher degree of uncertainty adversely affects the probability that a firm will adopt a new technology. Likewise, a high degree of certainty will increase the chances that a firm adopts a new technology. (Jensen, 1982)
Information Spillover Effects	Information spillover is the ability of a firm to observe the actions of its rivals and to make its own plans for adoption accordingly. (Mariotti, 1992)

Cost of Information Collection	Often the decision to adopt requires the firm collect a substantial amount of information regarding the new technology. The higher the cost of collecting this information, the more likely that the decision to adopt will be delayed. (Bhattacharya, 1986)
Anticipation of New Improvements	When there are large improvements anticipated there is a higher likelihood that a firm will delay the adoption decision. On the other hand, if new improvements are irregular it is more likely that a firm will choose to adopt. (Weiss, 1994)
Price and Entry Regulations	Price and entry regulations may slow the adoption of new technologies by making preemptive strategies that are designed to create a first mover advantage unattractive (Riordan, 1992)

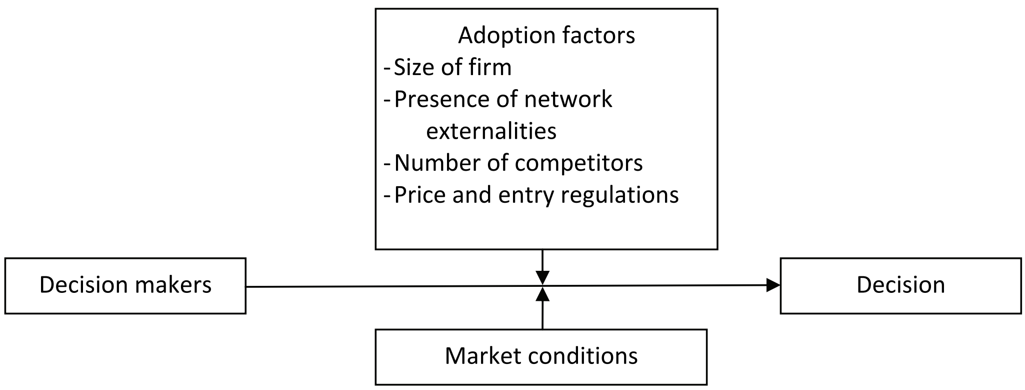

Figure 2 Conceptual Model

3. Methodology

The outcome of the decision process, i.e. the decision to adopt can be compared with the occurrence of adoption factors across nations. We selected five countries for a comparison. The five countries selected are the top-5 solar energy producing countries: Germany, Italy, Japan, Spain, and the United States.

A five-point scale was developed for each of the four adoption factors as well as for the dependent variable, i.e. adoption rate. This is shown in table 3. Data was obtained from industry sources such as the American Solar Energy Society, European Photovoltaic Industry Association, US Census Bureau, Statistics Bureau of Japan, sources such as the The Solar Review, Photovoltaics World, Renewable Energy, and for example Runci (2005), Reel (2006), Mints (2011).

4. Results Analysis

The results of our numerical scales are compiled in Table 4. This table lists the relative degree that each of these factors affects a firm in the given countries and compares it to the dependent variable, which is the degree of acceptance of solar power in each country.

Table 4 Comparative Presence of Adoption Factors

Factor	Country				
	Germany	Italy	Japan	Spain	USA
Size of firm	5	1	3	1	1
Network externalities	3	3	1	1	5
Number of competitors	4	4	3	5	5
Price and entry regulations	3	2	3	3	5
Degree of adoption	5	3	1	1	1

5. Discussion and Conclusion

5.1 Discussion

Table 4 shows that none of the four adoption factors can explain the adoption rate by itself. For example, Italy scores the same as Spain and the USA on the 'size of the firm' but has a different adoption rate. Germany and Italy score the same on 'network externalities' but have a different adoption rate. The same applies to the 'number of competitors'. For 'price and entry regulations' Germany, Japan and Spain have the same score yet their adoption rates are different.

The combination of factors also cannot explain the adoption rate differences. For example, the USA scores high on three of the four factors yet has a low adoption rate. This could mean that the one factor for which the USA scores low (size of firm), is more important in explaining adoption rates. Yet, Japan scores higher on this factor but also has a low adoption rate. Furthermore, Italy has the same score on the 'size of firm' as the USA but has a higher adoption rate. Based on our study, no definitive conclusions can be reached with regard to adoption factors that explain international adoption rate differences.

Table 3 Adoption Factor Measures

Factor	1	2	3	4	5
Adoption degree	There is a total peak power capacity below 5,000 MW installed in the country.	There is a total peak power capacity between 5,000 and 10,000 MW installed in the country.	There is a total peak power capacity between 10,000 and 15,000 MW installed in the country.	There is a total peak power capacity between 15,000 and 20,000 MW installed in the country.	There is a total peak power capacity above 20,000 MW installed in the country.
Size of firm	There is an average output per firm below 100 kW.	There is an average output per firm between 100 and 400 kW.	There is an average output per firm between 400 and 700 kW.	There is an average output per firm between 700 and 1000 kW.	There is an average output per firm above 1000 kW.

Presence of network externalities	CO_2 emissions are below 1 million tons annually with below 10 trillion kWh of electricity imported annually.	CO_2 emissions are between 1 and 2 million tons annually with between 10 and 20 trillion kWh of electricity imported annually.	CO_2 emissions are between 2 and 3 million tons annually with between 20 and 30 trillion kWh of electricity imported annually.	CO_2 emissions are between 3 and 4 million tons annually with between 30 and 40 trillion kWh of electricity imported annually.	CO_2 emissions are above 5 million tons annually with over 50 trillion kWh of electricity imported annually.
Number of competitors	There are less than 10 firms per million capita	There are between 10 and 20 firms per million capita	There are between 20 and 30 firms per million capita	There are between 30 and 40 firms per million capita.	There are more than 50 firms per million capita
Price and entry regulations	There are no mechanisms designed to support the implementation of PV power.	There are between 1 and 4 mechanisms designed to support the implementation of PV power.	There are between 5 and 8 mechanisms designed to support the implementation of PV power.	There are between 9 and 11mechanisms designed to support the implementation of PV power.	There are 12 or more mechanisms designed to support the implementation of PV power.

5.2 Conclusion

This purpose of this study was to examine international differences in adoption rates for new technologies. The solar industry was selected for a case study and five countries were selected for a comparison. Based on a literature review, four potential adoption factors were selected for the comparison. Based on the findings, none of these factors can explain the international adoption rate differences in the solar power industry.

Several limitations may have played a role in the results of the study. First, not all of the variables were standardized. For example the CO_2 emissions and amount of energy imported annually were not standardized by population because the presence of these factors in greater abundance in larger nations may play a role adoption. However, the disadvantage of this approach is that it may have over-stated this measure for larger countries.

Another limitation may have been the use of only one time frame. There were no apparent patterns that emerged from looking at the data across one single time frame, but perhaps if the data had been examined across time and the numerical scales had been presented throughout the history of solar power the results might have been different.

The third limitation was the lack of available information on the effect of public policies on adoption decisions. Public policies can potentially play an influential role in the adoption of new and unproven technologies and it is an area in which there has been very limited research. A recommendation for further research would be to look at how this factor may affect the adoption of new technologies.

References

Beck, F. (2006) ‘Photovoltaics’, *Renewable Energy Fact Sheet*, Environmental and Energy Study Institute, May. Obtained from http://files.eesi.org/photovoltaics_0506.pdf.

Goetzberger, A. and Hoffmann, V. (2005) *Photovoltaic Solar Energy Generation,* Springer, Germany.

Hoppe, H. (2002) ‘The Timing of New Technology Adoption: Theoretical Models and Empirical Evidence’ *The Manchester School,* Vol 70 No.1, pp. 56-76.

Keating, T. (2012) ‘Death to PV Subsidies’ *Photovoltaics World*, February 3

Marques, A.C. and Fuinhas, J.A. (2012) ‘Are public policies towards renewables successful? Evidence from European countries’ *Renewable Energy*, Vol. 44, August, pp. 109-118.

Mints, P. (2011) ‘Solar PV, CSP and CPV – Smoke and Mirrors’ *Renewable Energy Focus U.S.*, January/February 2011.

Reel, M. (2006) ‘Brazil's Road to Energy Independence’ *Washington Post* Foreign Service August 20.

Runci, P. (2005) ‘Renewable Energy Policy in Germany’, *Pacific Northwest National Laboratory Technical Lab Report* PNWD-3526.

Solaredge Technology (2012). Company website: www.solaredge.com.

Zweibel, K. (2009) “The Solar Review. In PV Fast Facts” Obtained through http://thesolarreview.org/2009/10/16/pv-fast-facts/.