Creation and shaping of the global solar photovoltaic (PV) market

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Abstract

Purpose: This chapter seeks to place Paris agreement on anthropogenic greenhouse gases (COP21) in a wider picture on how the global solar photovoltaic (PV) market has been created and shaped over decades. The chapter discusses the role of solar PV actors, as well as other actors in market shaping process. The aim is to show how the COP21 can be interpreted in a longer historical perspective.

Approach: The book chapter builds on expert interviews conducted after the COP21, as well as secondary data on historical studies on evolution of solar energy markets in various countries.

Findings: Although scientists and entrepreneurs have been important in creating and shaping the global solar PV market, it is noted that also other actors have had influence on the market development. Particularly, politicians are seen as having crucial role through legislation and funding. Unfortunate to solar PV market, support has fluctuated over time. The COP21 provides a clear pathway for positive support, and it is expected to bind governments for pro-solar politics even during low prices of fossil fuels and economic downturn.

Practical implications: The chapter provides an overview of what has happened in the history of global solar PV market. It gives reasoning why the COP21 is important in securing support to solar PV market. Thus, it can provide reasoning why the COP21 can make difference.

Originality/value: This is the first academic study that portrays the COP21 against historical evolution of global solar PV market.

Keywords: solar; photovoltaics; market; Paris; climate; COP21

Biography

Valtteri Kaartemo is University Teacher at Turku School of Economics, University of Turku, Finland. Kaartemo is a coauthor of several books, book chapters, conference papers and peer-reviewed articles. His research interests are market shaping, service research, innovation management, international entrepreneurship, value co-creation, and particularly various processes in and around these phenomena. Kaartemo is also Head of Research at Masar Academy, a research arm of Masar, a smart energy company primarily focusing on deploying mobile solar power plants in the Middle East and North Africa (MENA). Kaartemo is also currently co-directing a documentary on the development of solar energy markets in the MENA region.

Introduction

Solar photovoltaic (PV) is considered to be a crucial part in fight against climate change. The extensive use of fossil fuels has increased the amount of atmospheric carbon dioxide, and the change to renewable energies is considered as a viable solution (Sims, 2004). Generating energy with solar PV does not cause any carbon emissions, and can thus cut greenhouse gases. It is also acknowledged that research findings indicate that solar PV is a cost-effective way to cut greenhouse gases, and that the potential of solar PV in replacing fossil fuels increases, as the PV market grows (Duan, Zhang, Zhu, Fan, & Wang, 2016) depending on the energy mix used in the grid (Liu, Hoekman, Robbins, & Ross, 2015). The global installations of solar PV has expanded rapidly over the past few years, and reached about 250 GW in 2015 (Hill, 2016). Nevertheless, this only satisfies around 1 percent of world aggregate electricity demand. In order to advance positive development of the market, it is important to understand how various actors have contributed to the expansion of the global solar PV market till date.

The history of global solar PV market is already fairly long. It took more than 100 years from Edmund Becquerel discovering PV effect in 1839 to the commercial use of PV by Sharp in electronic calculators and by Philips in transistor radios in 1970s. Technologically, a lot happened in between: Willoughby Smith discovered the photoconductivity of selenium (1873); Charles Fritts created the first selenium-based solar cells (1883); Russell Shoemaker Ohl unintentionally found current flowing in a broken silicon sample at Bell Labs (1940); and Ohl's colleagues at Bell Labs, Daryl Chapin, Calvin Fuller and Gerald Pearson, demonstrated the first silicon-based solar cell (1954). ("This Month in Physics History April 25, 1954: Bell Labs Demonstrates the First Practical Silicon Solar Cell," 2009) Since then, efficiency of solar cells has improved remarkably, which now enables wider scale adoption of solar PV. However, as much as we are indebted to these great scientists, there is a far richer story of how various events has caused the global solar PV market to evolve over the past decades.

One of these events occurred in Paris in December 2015, when a universal agreement was made in COP21 to cut anthropogenic greenhouse emissions by 2020. COP21 pledges will be met by increasing energy efficiency as well as use of renewable energy. Solar PV has a tremendous role in meeting these targets. International Energy Agency (IEA) expects that COP21 requires increasing investments in renewable energy and International Renewable Energy Agency (IRENA, 2015) called COP21 as "a watershed for the global energy transition". It is considered that the global carbon dioxide emissions from energy use can be reduced by 35% by doubling the share of renewable energy in the energy mix by 2030 (IRENA, 2016). Here, solar PV has most growth potential. In fact, solar PV is projected to grow sevenfold, from around 250 GW in 2015 to 1,600–2,000 GW by 2030, with an outlook of becoming as important source of power as coal, natural gas, wind and hydropower (IRENA, 2016). This means that annual installations of solar PV should more than double over the next few years.

Only a month after COP21, I witnessed several companies discussing deployment of solar energy in the World Future Energy Summit in Abu Dhabi. Were these discussions initiated by the climate agreement in Paris or what is the meaning of COP21 to the evolution of the global solar PV market? This book chapter discusses the evolution of the global solar PV market till date from the perspective of solar energy actors, other business actors, and politicians. In the end, COP21 is portrayed in the bigger picture of creation and shaping of the global solar PV market.

It is argued here that global solar PV market is not isolated from what happens in the rest of the society. As noted by Bohnsack et al. (2015) different actors, at different times, created the momentum for the industry's evolution due to institutional shifts. There have been needs for new

regulatory frameworks, technological standards, and business models. Most of all the institutional development has been driven by interplay between public and private actors that influenced one another over time and across national borders. In terms of innovation policy, Tsoutsos and Stamboulis (2005) discussed how renewable energy technologies differ from conventional systems due to their linkage to the whole energy system. New ideas do not diffuse easily but require changes in both supply and demand. For instance, the demand and supply has till date been largely influenced by changes in price and availability of other forms of energy, such as coal, gas and oil (Bohnsack et al., 2015; Jones & Bouamane, 2012). To illustrate, exhaustion of Britain's coal reserves in the 1860s, periodic oil and coal shortages during and after World War II, the OPEC oil embargo in 1973, and warnings about the risks of nuclear energy have all encouraged scientists, inventors and policymakers to seek alternative sources of energy (Johnson, 2015). From today's perspective, it is interesting to note that these changes were not that much driven by environmental concerns. In this sense, it can be considered that COP21 is positioned in one extreme corner of events influencing the evolution of the global solar PV market.

This book chapter is based on expert interviews and online interaction after the Paris climate agreement in December 2015 as well as prior literature on solar PV markets. Based on the primary and the secondary data, a closer look is taken on what is known about the creation and shaping of the global solar PV market.

Solar PV actors

Global solar PV market has been driven by solar PV actors, who have deliberately or unintentionally contributed to the creation and shaping of the market. Here, I focus on entrepreneurs and companies in creating the market.

Solar PV market got early attention with collaboration between science and commercial actors in 1950's, and an Association for Applied Solar Energy was founded in the United States already in 1954. It organized conferences which enabled interaction between scientists and small entrepreneurial firms. (Jones & Bouamane, 2012) Unfortunately, these firms were too small to get things done on a larger scale. They were mostly focusing on powering spacecrafts, off-grid telecommunications stations and lighthouses (Kimura & Suzuki, 2006). These projects helped companies to get some return on investments but that was not enough for scaling up or investing in research that was necessary to ramp up mass production.

In Japan and Europe, solar PV companies did not even have domestic space programs to boost the industry that was helping out in the United States. Instead, companies needed to rely on government-funded demonstration projects (Kimura & Suzuki, 2006). In Japan, solar PV companies were, therefore, looking at opportunities overseas. Eventually, there were small projects, such as Kyocera's delivery of PV panels to a microwave telecom relay station in the Peruvian Andes (Jones & Bouamane, 2012). Later, large Japanese electronics companies combined their forces to lobby for market creation in Japan, which until 1980's did not see any commercial interest in PV utilization. Companies like Kyocera, Sanyo and Sharp established Japan Photovoltaic Energy Association (JPEA), through which they lobbied for more PV-friendly politics. (Kimura & Suzuki, 2006)

PV companies got more financial resources in 1970's; particularly after the second oil crisis. This was the time when major oil companies entered the market. They were brought to the field by opportunities in powering their offshore business. The oil companies hindered the development of the market, as solar energy startups did not have enough financial resources to compete against well-funded multinationals (Jones & Bouamane, 2012). They should have been powerful enough to

change legislation toward PV. However, solar energy remained to minor in their diversified strategy that they did not have enough incentives to disrupt their core businesses. Particularly, as alternative energy sources were not able to return as high profit as they had used to earn from petroleum business. Nevertheless, based on their multi-million investments in solar PV it seems that they were in the business for real. Yet, final effort for market shaping and creation was never done by them.

Later, government actions, economical situation and other factors, which are discussed later, helped creation of the market and created a boom in PV manufacturing. This stimulated emergence of solar PV manufacturers, who were solely concentrating on the panel production (Jones & Bouamane, 2012). Perhaps, the greatest leap from solar PV companies came from China, when companies entered PV panel production massively after 2005. This drove down the prices of panels and had massive influence on the global solar PV market (Johnson, 2015). Lower prices distracted oil giants, such as Shell and BP from the business and led to bankruptcies of the US and European PV manufacturers, who were not able to cut their costs as fast as the Chinese (Jones & Bouamane, 2012). The crisis of Western PV manufacturers was deepened when there was overcapacity in the market, particularly since 2009. On one hand, this lowered the prices, which was good for the price competitiveness of solar PV against fossil fuels. On the other hand, overcapacity caused trouble for manufacturers of high quality panels and diminished the attractiveness of panel manufacturing as an investment target.

In the development side, there have been numerous companies with various business models. They have been learning from each other, copied some of the best practices and thus created market practices for others to follow. For instance, the founder of SunPioneer started drafting his business plan by modifying a full contractual structure for another renewable energy technology (Overholm, 2015).

Other business actors

As global solar PV market has emerged it has been characterized by novel paradigm in energy generation. There are several actors and institutional forces that influence the system (Nagamatsu, Watanabe, & Shum, 2006). Therefore, I introduce these actors and briefly discuss their role in the shaping of global solar PV market. Here, it is noted that the ecosystems vary from one country to another. Further, solar PV market has been influenced by development in other industries, particularly other natural resources (Bohnsack et al., 2015). Therefore, a closer look is taken at multiple actors in the following.

Consumers

The role of consumers in creating and shaping global solar PV market has not been covered in detail. There are some indications of identifying early adopters. For instance, (Jones & Bouamane, 2012, p. 33) report on how US entrepreneur Wayne Robertson experimented with solar panels for years before he started selling them in early 1980's. The early adopters are presented as follows: "…where I lived, there was a lot of people who living off the grid and with a similar mindset as us (…) there were also marijuana growers living around that had lots of money and were willing to try new things (…) those were our first clients". Otherwise, the role of early adopters and consumers in general has been considered as modest or is not discussed at all.

Utilities

One of the most powerful actors in the energy field are electric power companies, who were not voluntarily promoting adoption of solar PV in 1980s. This was a real problem, for instance in Japan,

where the country's ten largest electric companies controlled the energy market (Jones & Bouamane, 2012). Kimura and Suzuki (2006) consider that energy companies were even opposing the development, as they did not consider benefiting from renewable energy sources. Particularly, renewable energy sources were considered as unreliable and due to their intermittent characteristic they might have been very expensive for secure energy delivery. As a result, electric companies were reluctant to open the grid for independent power producers who they could not directly control. They were able to keep solar PV power generators away from the grid by own means as well as promoting discriminating legislation.

The impression of utilities against solar PV was changed with the help from a large demonstration project by Japan's New Energy Development Organization (NEDO). The purpose was to examine the influence of 100 house-like buildings with a 2kW PV system each on the grid. The results were positive, indicating that solar PV is reliable and safe. As a result, the electric power industry started accepting distributed PV systems. (Kimura & Suzuki, 2006)

In Japan, the government's plans to increase deployment of renewable energy encouraged electric power companies to proactively starting a net-metering system to enhance renewable energy installations. As a result, they paid the same price as the residential electricity rate for PV system owners, which made the program very attractive to households. (Kimura & Suzuki, 2006)

Fossil fuels

The interest in solar energy and later to solar PV has always been influenced by the price and availability of fossil fuels. Already in 1920's the solar water heater business by William Bailey was hit by the introduction of cheap gas in California (Bohnsack et al., 2015). Every once in a while the price of fossil fuels has gone up and the interest in solar PV has evoked. For instance, the oil crises in 1970's as well as the crisis in the Persian Gulf a decade later encouraged to focus on energy independence in oil-consuming countries. (Bohnsack et al., 2015) On the other hand, when prices of fossil fuels have come down and the availability improves, this has shifted the attention away from the potential of solar PV.

The cost of oil came sharply down from the peak price of oil crisis, and throughout 1980's remained significantly below previous heights of the past two decades. As a result, there was less interest in promoting solar PV (Jones & Bouamane, 2012). But it was not only the world price of oil but availability of fossil fuels that was of interest. For instance, Israel was afraid of being cut of oil supplies from the Middle East. This encouraged small scale experimenting on solar PV in Israel. (Jones & Bouamane, 2012)

Also discoveries of natural resources have changed interest in solar PV. For instance, discovery of large gas field at Groningen and discovery of oil and gas in the North Sea distracted the Netherlands and the United Kingdom from active development of global solar PV market, respectively (Jones & Bouamane, 2012).

Unfortunate to solar PV, not always the price and availability concerns have led to the increasing interest in solar PV installments. Instead, in some countries this has encouraged more focus on nuclear, such as in Sweden and France, as well as other renewable energy sources. For instance, Japan which launched Project Sunshine simultaneously promoted nuclear power as a solution to energy security issues (Jones & Bouamane, 2012).

Nuclear energy

Immediately after the World War II, there was not much need for finding alternative sources of energy. And particularly nuclear fission was considered as a way to eventually power the planet with unlimited and cheap energy. As a result, interest in solar eroded.

However, nuclear incidents have played for increasing interest in solar energy over past decades. In 1979, the accident at Three Mile Island in the United States caused Shell to sell its assets in nuclear business, and encouraged it to focus on renewable energy sources later. In 1986, The Chernobyl accident impacted Germany heavily, and partly initiated increasing support for alternative energies. More recently, the Fukushima incident in Japan in 2011, diminished general interest in nuclear (Johnson, 2015).

Other renewables

Also other renewable energy sources, like wind and hydro have influenced the global solar PV market. On one hand, they have been sharing research funding. On the other hand, they have provided more alternatives for sustainable energy investments and solar PV market have learnt from the market development, particularly in wind sector, as it has exceeded solar energy in major countries (Sakata, Sasaki, & Inoue, 2011). Despite China has been promoting solar PV panel production over the past decade, in their own energy production they have been more in favor of wind and biofuel (Jones & Bouamane, 2012). This has led to steady flow of cheap Chinese PV panels to the world market.

Interestingly, also experiences in solar thermal and thin film have influence on solar PV market. (Kimura & Suzuki, 2006) shared a story of two solar thermal demonstration plants in Japan, which had weak performance. These results led to termination of solar thermal research funding and the money was allocated to solar PV, as the Ministry of International Trade and Industry (MITI) was reluctant of giving up the money they had negotiated to the solar energy.

Electronics and silicon

PV cells are made of silicon. Adoption of crystalline silicon for PV production enabled the solar PV companies to learn from electronics sector, which is also largely silicon-based (Nagamatsu et al., 2006). No wonder the first large companies, who got interested in solar PV were electronics companies. Solar PV market benefited from the experience of electronics companies in mass production, and wider interdisciplinary development and spillover learning in development (Nagamatsu et al., 2006). This also helped bringing in more academic interest than wind, for instance (Sakata et al., 2011).

The price of silicon was rising until the financial crisis, as PV panel manufacturers were competed for the polysilicon with electronics companies. Yet, the prices crashed as a result of weakening demand of electronics. In addition, the emergence of specialist polysilicon manufacturers helped achieving economies of scale and decreasing the price (Jones & Bouamane, 2012). This has lowered the price of solar PV panels, and as a result improved their cost competitiveness against other sources of energy.

Financers

Often, the role of finance is overlooked in studies on the history of solar energy. However, the role of venture capitalists should not be overlooked, as they provided private funding for solar companies. The interest in the financial market has been important in finding funds for solar PV

installments. There have also been finance innovations over the past few years with an introduction of yieldcos. They have enabled collecting finance for PV on the stock market.

General interest in sustainability has encouraged banks and pension funds to divest conventional energy assets. The change in the financial sector has not been easy and has required actions from solar energy actors. For instance, pioneering companies have educated bankers and insurance companies which has also helped others when these companies have developed their services for solar PV companies (Overholm, 2015). At the moment these services are available in developed countries, but the lack of robust financial markets in developing countries is still considered as a barrier for solar investments in developing countries(Herrera-Cano & Gonzalez-Perez, 2016).

Politicians

Over years, governments have played role hindering and fostering the development of solar energy in general. For instance, the French government decision not to provide further funding for August Mouchet to develop his solar steam-powered plant, or the struggle for convincing the Ministry of Finance in Japan to finance solar energy subsidies, or the US preference for defense and space contracting indicates that political decision-makers have not always made decisions to boost the development of the global solar PV market (Jones & Bouamane, 2012; Kimura & Suzuki, 2006).

World Wars have had great impact on the evolution of global solar energy market. For instance, one of the most promising stories of wider scale adoption of solar energy took place in Egypt before the First World War but it was postponed because of the War. On one hand, the World Wars have influenced greatly the economics and the price of fossil fuels, as the economic situation has been bad after the wars. On the other hand, conflicts have also raised questions on energy security and independence, which in turn has encouraged wider adoption of solar energy.

Wars or not, there has been constant interest in alternative sources of energy over the fossil fuel age. What we saw during the twentieth century imperial expansion, the advent of the Cold War, in the middle of the Cold War, is basically not that different from the more recent emergence of sustainability-based global energy and environmental politics (Johnson, 2015). Solar was first more of a question of power politics and afterwards became more of a symbol of countercultural and environmentalist visions of future. Anyway, interest in solar PV as an alternative to fossil fuels has resulted in different actors. In this section I discuss the causes for political actions as well as how they manifested as pro-solar legislation, finance, support to research, and market creation.

Whereas solar PV is now framed as a sustainable, renewable, clean source of energy, it is worth acknowledging that environmentalism has not always been the key issue in finding alternatives to fossil fuels. The United Nations Conference on the Human Environment in Stockholm in 1972 launched an Environment Program, which discussed the potential of solar energy as a clean source of energy. Two years later, the Ford Foundation's report talked in detail about the greenhouse effect caused partly by the use of fossil fuels as well as the risks of nuclear power. Although solar PV was not thoroughly discussed, it was discussed that solar energy had potential, and only required public money being poured in to get developed. (Jones & Bouamane, 2012)

Although this did not result in radical shifts in legislation or finance, the acknowledgement of climate change insisted governments to focus on developing clean technologies also in 1980's when the price of oil was low and availability was not an acute problem. Concerns over the climate change peaked at the international conference on the changing atmosphere in Toronto in 1988. That was the event where large international community shared a consensus that climate was warming

and that warming was actually anthropogenic. As an aftermath of the conference, a number of countries in Europe announced cutting their greenhouse gas emissions voluntarily. Further, there was interest in finding a global agreement in cutting the emissions. In the first Ministerial Conference on Air Pollution and Climate Change in 1989 in Nordvijk, the Netherlands, the participating countries were able to compromise on stabilizing the level of greenhouse gas emissions at the 1990 level. Although this was not legally binding, it later had influence on domestic energy policies. (Kimura & Suzuki, 2006)

The discussions on and around the climate change only intensified after that meeting, and increased the attention for solar energy in the US, Germany and Japan. Particularly, there was more evidence on climate change in the first decade of the 21st century. This was important as the inexact data on the sources of climate change had earlier given an excuse to governments to focus on more acute financial and economic issues. As evidence on the role of fossil fuels on climate change mounted, environmental activists also started lobbying for wider adoption of solar energy. (Jones & Bouamane, 2012).

Legislation

Governments have initiated various regulations and laws which have had influence on the creation and shaping of the global solar PV market. Sometimes, their initiatives have been against wider scale adoption but we have also witnessed laws that have clearly boosted the emergence of the market. Occasionally positive results on solar energy have been inadvertent.

One of these laws that had positive influence on the global solar PV market was the US prohibition of disposing lead-acid batteries from offshore platforms in the sea (Bohnsack et al., 2015). Solar PV cells replaced the batteries creating demand beyond spacecraft industry. In addition, this brought oil companies into the solar PV market. Another example of unintentional acts was the Public Utility Regulatory Policies Act (PURPA) in 1978, which required utilities to purchase electricity from independent power producers (Bohnsack et al., 2015). Although this was initially planned for gas companies, it later benefited wind and finally solar power generators, as it gave them access to sell solar energy directly to utilities. Similar examples of unintentional solar friendly legislation can be found from the UK, where the Non Fossil Fuel Obligation was introduced in 1990. It required regional electricity companies to purchase power from independent power producers at a premium price .This was initially designed to support nuclear industry but solar and wind producers were also included in the obligation. Unfortunately, the obligation encouraged gaming and further auctioning, which eventually did not support local solar PV market. (Jones & Bouamane, 2012)

The influence of PURPA was extended with the introduction of the Energy Tax Act that provided 30% credit for consumers buying solar and wind energy equipment (Bohnsack et al., 2015). It also enabled 10% investment tax credit for businesses (Jones & Bouamane, 2012). In 1980's not much happened in boosting renewable energy, as the focus was more on economics and finance during the Reagan Administration. During the Clinton Administration there was an increase in gasoline taxes. During George W. Bush presidency, the Investment Tax Credit was relaunched giving 30% of the expense back to businesses investing in solar energy projects. This initiative gained from the financial crisis, as it was extended by eight years. (Jones & Bouamane, 2012)

Similar subsidies were introduced later in Germany, when the country launched 1,000 roof program for PVs in 1990. In the program, the German government and the state governments promised to cover a significant portion of the investment cost of solar installments. This was massively extended in a 100,000 roof program in 1999. More importantly, Germany was the first country to introduce feed-in tariff legislation that forced utilities to connect independent power producers to the grid and

buy the electricity they generated for pre-negotiated price (Jones & Bouamane, 2012). Although the initial impact was minor, as the feed-in prices were too low compared to the production costs of solar panels, it attracted early adopters. It became a domestic success story when the act in 2000 revised feed-in tariff rates below the solar energy production costs. By 2008 already 500,000 Germans had installed solar systems. And even more importantly, the initiative was widely copied and modified internationally. Thus, it had huge impact on the evolution of the global solar PV market. (Jones & Bouamane, 2012)

In Japan, the government simplified procedures of PV installation and technical guidelines for grid-connection in 1990's. Earlier complex regulation had increased the cost of solar energy installations. In addition, Japan introduced investment subsidies for residential PV systems, and the net-metering system to create local solar PV market. (Kimura & Suzuki, 2006) This was widely needed as local PV panel producers had struggled for lack of domestic market for already a couple of decades. After Fukushima accident, Japan announced "Strategy for the Rebirth of Japan" and a related feed-in tariff sponsoring program for PV (Palz, 2014).

One of the success (as well as failure) stories in the role of authorities in shaping the market is Spain. Spain had a progressive renewable energy framework, and implemented generous subsidies and feed-in tariffs to support solar energy. Many cities had regulations for obligatory installation of solar PV on new buildings. This was further spiced up with simultaneous liberalization of energy markets, which led to hike in electricity prices. (Glinavos, 2016) By 2009, Spain had become the world leader in terms of the share of electricity generated by solar (Jones & Bouamane, 2012). However, things changed rapidly when Spain was hit hard by the global financial crisis. Tariff deficit that the government owed utilities grew rapidly to billions of euros, and the government needed to revise the tariff system. They even published a decree which influenced existing plants retroactively. This deteriorated the viability of many PV projects in Spain, and set the local market at halt. (Glinavos, 2016)

Although the Spanish experience is probably influencing the cost of money for solar developers, even greater impact on the development of the global solar PV market originated from China's Renewable Energy Law which was implemented in 2005. The law promoted development and utilization of renewable energy. The law later required electricity companies to buy electricity from independent power producers. Also subsidies and feed-in tariffs were introduced. As measures these were not novel but this increased the number of Chinese panel producers, creating overcapacity and lowering the prices remarkably. Making eventually PV solar cost-competitive in many parts of the world.

Finance to research and commercialization of solar PV

In addition to legislative changes, the governments have supported installation of solar PV by providing access to finance. Public policies for promoting low interest rates have in fact made the market in this capital-intensive industry. In late 1990's solar energy developers typically faced interest rate in the 8–10% range. When the German development bank launched the program 1.75% for a 10-year loan, it eventually made the domestic market. Similarly, the public funds provided through subsidy program to finance residential consumers in Japan also had tremendous impact on developing local demand (Kimura & Suzuki, 2006).

Further, in China solar electricity users benefited from subsidies but also Chinese PV panel manufacturers largely benefited from low interest rates and favorable land deals. In the United States, the Federal government employed stimulus package to provide multi-million loan guarantees

to solar energy companies. In Europe, the crisis instead cut public finance, and several companies went bankrupt, and PV manufacturers were forced to move their production to China. In the bigger picture, this was no news, as companies have already since 1970's been moving to countries were finance has been available. (Jones & Bouamane, 2012)

In addition to providing finance in the commercialization phase, the role of public finance has been important in supporting research. Often, the business cases were far in the horizon in up to 20 years, so it was understandable that many companies could not have afforded the research and development without government intervention. However, the governments' interest in supporting research in solar has fluctuated over time. At times when countries were shocked by threat of war, changes in the availability of energy and hikes in petroleum prices authorities have become more interested in energy independence. There solar PV research has had its stake among other alternative energy sources. Evidence shows that public spending not only helped researchers but also induced commercial PV research and development expenditure. Unfortunate to solar PV, shocks in energy security were fast forgotten and there was more interest in more acute economic and financial issues, which cut public spending on solar research.

Creating and facilitating demand

Governmental organizations have also been important actors in creating and facilitating demand for solar PV. For instance, the US space program was the primary customer in the US solar industry. This attracted electronics companies to the market but did not boost terrestrial solar market directly, as cost of solar PV was not an issue in expensive space programs (Nagamatsu et al., 2006).

Governments have also given promises for future market development by saying aloud future targets for the share of solar energy in power generation. This has been an indication to companies that 10–20 years there will be a significant market for their products, and it is therefore worth developing solar PV technology. This happened for instance in Japan, where government had clear targets for solar energy, as well as helped creating local demand through demonstration projects with ambitious cost reduction targets (Kimura & Suzuki, 2006) encouraging PV manufacturers to mass production learning (Shum & Watanabe, 2007). In the end, the government intervention in Japan, or the Sunshine Project (R&D program on new energy) in particular, has been thanked for creating a "virtuous cycle" between R&D, market growth and price reduction (Watanabe, Wakabayashi, & Miyazawa, 2000)

Discussion

Over years, the global solar PV market has been created and shaped by various actors. Next, I discuss how and why these actions are interlinked. Over time, PV has faced various barriers for widespread adoption, as it has needed to overcome the so-called carbon lock-in effects, i.e. the role of fossil-fuel based centralized energy generation regime (Shum & Watanabe, 2007). During the times when the price of solar PV panels were far from being cost competitive against fossil fuels, it was important that there were pioneers, who saw potential in developing an alternative source of energy that is clean and widely available. As noted above, the private market has not been able to boost wider scale adoption and therefore government intervention has been needed. Particularly, as startups lacked financial means and strong actors, such as utilities and oil companies, did not have immediate interest in disrupting their core businesses by changing the dominant regime in electricity generation, it was necessary that public actors supported the market development through legislation, finance and purchases.

One of the latest interventions of this kind is the COP21 agreement that was signed in Paris in December 2015. The COP21 guarantees that majority of the countries are bound to support wider scale adoption of solar PV, even if there were economic recession or if the price of fossil fuels came down. This is crucial as we have witnessed that economic downturns have earlier influenced the solar PV market tremendously. In fact, general economic situation has had three-fold influence on the global solar PV market. First, recession has typically increased the availability and cut down the prices of fossil fuels, making alternative energy sources less attractive. This was witnessed after the world wars, during great recession, in 1980's and also in the aftermath of the global financial crisis. Second, economic recession typically requires tighter budget and that has led to cuts in public spending on solar energy subsidies as well as research expenditure. This is also what happened in Europe recently after the global financial crisis. Third, and on contrary, economic recession can also increase public support to solar energy, as countries need new approaches to boost the economy. For instance, the US stimulus package can be seen as an example here. Nevertheless, it is expected that COP21 reduces uncertainty in governmental support to renewable energies, and is thus considered as beneficial to the long-term evolution of global solar PV market.

There are already a lot of evidence of both technology-push and demand-pull policies that have promoted local solar PV markets (Kimura & Suzuki, 2006), and increased commercial investments in technology exploration (Watanabe et al., 2000). As companies prefer investing in exploration of mature technologies, this is most probably beneficial to solar PV compared to other alternative sources of energy (Hoppmann, Peters, Schneider, & Hoffmann, 2013). Even though "PV" or even "renewables" are not explicitly mentioned in the COP21, the agreement provides long-term horizon for developers and financiers that based on historical evidence is needed for positive market development. In addition to the direct effect, COP21 may also boost global solar PV market as a result of the indirect influence of the agreement. For instance, many financiers are already divesting their fossil fuel-based assets and investing in new projects in oil and gas has become more challenging. This development in the fossil fuels may result in more financial resources in renewable energies and solar PV. In addition, lack of new projects may diminish the availability of oil and gas, which can increase prices, and make solar energy more competitive.

Although COP21 can be interpreted as an important facilitator in the market, it is worth acknowledging that incentives are not enough to create solar PV market (Overholm, 2015). Politicians can help creating attractive frames for market but eventually various actors in the service ecosystem are needed: from financiers to installers and end customers. Unfortunately, we still lack understanding of what motivates these actors in engaging in solar PV market.

I admit that it feels somewhat paradox to discuss about global solar PV markets. Whereas supply side is global by nature, the markets are still highly local on the demand side. Yes, solar cells and full PV modules are manufactured around the world in large automated manufacturing facilities. As not much labor is needed in the production, the labor costs are not critical and that does not explain why Chinese cells or modules are cheaper than others. (Palz, 2014) Yet, one needs to acknowledge that only PV modules and inverters are global by nature. Installation is in turn local, where labor costs matter more. That explains the differences in balance of system (BOS) costs, i.e., support structures, cabling et cetera. (Palz, 2014) Nevertheless, I consider it is appropriate to refer to global solar PV market, as the development of the market has been influenced by various events around the world affecting both supply and demand. As the findings by (Bohnsack et al., 2015) indicate, the transition of the solar industry can only be understood from an international viewpoint; it has been a process of competition between companies as well as between countries that operate in a globalized space. Over time, the center of gravity of the global solar PV market has shifted from a country to another.

In the technological side, I highlight the importance of international research collaboration in 1970's. As a result, scholars were able to set a global standard for solar photovoltaics that later enabled not only collaboration between research institutions and companies but economies of scale that were needed to cut down prices. On an institutional side, the feed-in tariff system was a major innovation to accelerate investments in the renewable energy by providing price certainty to energy producers. Also the Chinese government's role was decisive to support large-scale solar cell production in the early 21st century, which helped a number of Chinese manufacturers to enter the business and scale up their production. In the business side, some financial innovations, such as YieldCos enabled predictable cash flow to institutional investors, which enabled financing of large utility-scale solar farms. This all helped cutting down the cost of solar energy installments, and to attract further investments. Thus, by the COP21 in Paris we were already witnessing the situation that solar was price-competitive against fossil-based fuels in many regions without any subsidies. Yet, COP21 was positive news to the solar business.

Conclusion

This book chapter places Paris agreement on anthropogenic greenhouse gases (COP21) in a wider picture on how the global solar photovoltaic (PV) market has been created and shaped over decades. By increasing understanding of what has happened in the past, it is wished that future decisions would contribute to the positive market development. This is important as solar PV is already a cost-efficient way of fighting against greenhouse gases and it can be even more beneficial as the market expands. The chapter aims at showing how the COP21 can be interpreted in a longer historical perspective. The paper is based on expert interviews and online interaction after the Paris climate agreement in December 2015 as well as prior literature on solar PV markets. The findings underscore the importance of dynamics between various actors that are not always just focusing on the development of the solar PV market. The role of politicians has been crucial in creating a business environment that has attracted entrepreneurs, investors and established businesses with a long-term vision. COP21 can be interpreted as one of these interventions giving guarantees that governments remain supportive to the development of solar PV also during economic downturns and political turmoil. From time to time, there is volatility in the market but it is necessary that businesses believe in the long-term profitability of solar PV in order to keep on investing in it, as that is the most important way to bring down the cost and improve efficiency, and thus make it attractive in the private market.

This chapter contributes to the sustainability literature by showing how creation and shaping of renewable energy market requires proactive efforts from various stakeholders in the service ecosystem over decades. By showcasing a longitudinal process of the evolution of global solar PV market, the chapter also contributes to the market creation and market shaping literature that marketing scholars have recently paid focus on (Kjellberg & Helgesson, 2007; Storbacka & Nenonen, 2011).

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