Sunny or Sunless?

A Study of the Evolvement of the Technological Innovation System of the Chinese Photovoltaic Industry

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List of Abbreviations

PV –Photovoltaics

BIPV—Building Integrated Photovoltaics

IEA—International Energy Agency

GHG—Greenhouse gas

TIS—Technological innovation system

IPCC—Intergovernmental Panel on Climate Change

NSI—National System of Innovation

SSI—Sectoral System of Innovation

RIS—Regional Innovation System

R&D—Research and Development

SOE—State-owned Enterprise

CREIA—Chinese Renewable Energy Industries Association

CPVS—Chinese Photovoltaic Society

WB—World Bank

FIT—Feed-in-tariff

MOST—The Ministry of Science and Technology of the People's Republic of China

NDRP—National Development and Reform Commission

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1. Introduction

Energy demand in China is increasing rapidly driven driven by its highly energy intensive economy and strong GDP growth. According to prediction in World Energy Outlook released by International Energy Agency (IEA) in 2011, China's energy demand would increase by 75% from the 2008 to 2035. In 2035, its energy demand accounts in the world energy demand would increase to 22%. In 2000 the energy consumption in China was just half of it in the USA, while in 2009 China has surpassed the USA, becoming the country with the largest annual energy consumption amount. With an economy that is expected to maintain a rate of growth of 7–8% for decades (Crompton, Wu 2005), energy demand is definitely increasing.

As an emerging economy, China currently faces the serious situation of finding a balance between rapid economic growth and envrionmental impact. Despite of increasing demand, China's energy consumption structure has not changed much in the past decade. In 2001, China's primary energy was coal, as much as 62.0%, followed by oil at 27.6%. Hydroelectricity made up 6.9% of the primary energy consumed, and natural gas 3.0%, with nuclear power and other types of energy accounting for only 0.5%. In 2007 the proportion of coal rose to 69.46%, and oil dropped to 20.12%, while hydroelectricity, natural gas and nuclear power and others remained about the same at 6.32%, 3.34% and 0.76% respectively (Jin 2003, Lin et al. 2010). Fossil fuel comprised nearly 90% in China's energy consumption structure.

The primary fuel mix dominated by coal is contributing to significant local, regional, and global environmental pollution (Judith A. Cherni, Joanna Kentish 2006), with frighteningg environmental implication. Coal combustion is associated with the majority of particulates and nearly all of the sulfur emitted in

China. In 1993 total emissions of particulates and sulphur dioxide amounted to 14 and 16 million tons, respectively, with the non-power industrial sector accounting for about 44% of emissions, electric power 30%, the residential sector 16%, and transport 3%. The large amounts of coal used in dispersed and relatively inefficient industrial boilers and household stoves are responsible for a large part of China's air pollution (Johnson et al. 1997). And one-third of the entire country suffers from acid rain (Zhang et al 2010). The economic damage from air pollution caused by the burning of fossil fuels is estimated at 2–3% of the gross demestic product (Wang 2003). It is therefore urgent that China incorporates renewable energy sources with its energy consumption structure to mitigate environmental problems.

1.1 Research Questions

One of the key challenges facing China today is meeting its increasing energy demand to maintain economic growth while at the same time protecting the environment. It is therefore critical to change China’s energy consumption structure, shifting to a more sustainable energy strategy. The problem with inducing such shifts is that it poses a formidable task for policy makers, since it involves not only changes in technology, but also fundamental changes in production, organization, and the way people live their daily lives (Kemp 1994). This thesis examines the issues involved in changes in technological systems, focusing on the Chinese solar photovoltaic (PV) industry. By examining the specific technical, economic, institutional and social aspects of a transition to more environmentally benign technologies such as solar photovoltaic, this study explores the broader question of how technological innovation systems of Chinese PV sector evolved in past half century by addressing the following specific research questions:

1) How did the TIS of the Chinese PV industry first emerge?

2) What were characteristics of TIS at the formative stage of the industry?

3) How did the TIS evolve at the rapid growth stage?

4) What is the function pattern of TIS at the rapid growth stage? And what are its characteristics?

1.2 Rationale for Choosing the Topic

Since the Industrial Revolution in the mid 19^{th} century, technology has evolved at an astonishing pace and has impacted every aspect of life, contiunous improving people’s living standards. Products are updated in a very fast speed, facilitating people’s life.

However, certain problems remain unresolved such as poverty in underdeveloped countries, and environment problems like water pollution, air pollution, the reduction in biodiversity, diminishing food security, and the energy crisis, all of which are getting more serious. The public and governments have come to realize that, to some extent, economic growth is achieved at the risk of environment degradation, and it is crucial to take action to save the Earth.

Climate change has been a hot topic nationally as well as internationally in recent years due to its serious consequences might lead to. The general definition of *climate change* is a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause (Intergovernmental Panel of Climate Change 2001). However climate change usually specifically denotes climate change caused by human activity, as opposed to that result from natural geological processes (UN 1992). Ruddiman (2005) also argues that the impacts of human activity have existed for a long time, approximately 12, 000 years, but it increased dramatically 200 years ago. The time period is just in accordance with the first industrial revolution. Human impacts on the environment may have deep roots in history, but they apparently accelerated during and after the first industrial revolution as a result of the diffusion of hydrocarbon-based energy carriers and related technologies (Smith 2009).

The consequences of climate change can be catastrophic, such as Arctic ice loss, rising sea levels, and the chaning distribution and coverage of vegetation, all of which are ”largely irreversible” (Solomon et al. 2009). Anthropogenic changes, particularly greenhouse gas (GHG) increases, are probably responsible for climate change (Crowley 2000). Though GHG emissions could be traced to various sources, such as agriculture (Cole et al 1997), the consumption of fossil fuels is determined to be the main reason of climate change. According to Meinshausen et al. (2009), total anthropogenic emissions of 1 trillion tones of carbon equivalent to 3.67 trillion tones of CO_2, about half of which has already been emitted since industrialization began, results in “a most likely peak carbon-dioxide induced warming of 2^oC above pre-industrial temperatures” (P1163).

Even if the consumption of fossil fuels would not bring so many problems, there would not be abundant energy reserves to support human beings with current energy consumption speed for a long time. Under such circumstances, it is critical to find a solution to meet increasing energy demand. Renewable energy as a choice has been emphasized in many countries’ polices and budgets. The Renewable Portfolio Standard (RPS), a policy instrument to increase the production of electricity from higher-cost energy sources with desirable social and environmental benefits, is rapidly emerging as a popular mechanism among policy makers to increase the penetration of renewable energy in the electricity market (Berry, Jaccard 2001). To promote local wind energy deployment, Spanish government agencies have mandated the incorporation of local content in wind turbines installed domestically for a long time(Lewis, Wiser 2007). Germany has more than doubled its renewable electricity production since 2000, primarily due to a subsidy policy based on feed-in tariffs established in 1991 (Frondel et al. 2010). Experience in Europe have indicated that appropriate feed-in-tariffs (FIT) can lead to rapid growth in renewable electricity markets, promote strong manufacturing industries, and create thousands of new jobs in a cost-effective manner (Rickerson et al. 2007).

The development of renewable energy started at the same time as the foundation of the People’s Republic of China. Research of solar energy started in the 1950s, as well as small wind generators (Li et al. 1997). China’s central government is quite active in planning the implementation and dissemination of renewable energy projects and the industrial development of solar, wind, biomass, and other forms of renewable energy. China’s Renewable Energy Law was passed by Congress on February 28, 2005, and took effect on January 1, 2006. The issue of the renewable energy law indicates that the government has realized the strategic role of renewable energies in optimizing China’s energy supply mix, mitigating environmental pollution, improving energy supply security, and promoting rural social development; and directly relates the renewable energy development and utilization to China’s energy system transition (Zhang et al. 2010:4392). The importance of renewable energy has been recoganized by the government.

In recent years, China has made a significant progress in the exploitation and utilization of renewable resources, generating 2.5×10^5 GW in 2005 and comprising 2.5% of the country’s total consumed energy (Zhang et al. 2009). By 2007, the installed capacity and energy generation of hydropower totaled 145.26 GW and 486.7 TWh, about 891 and 685 times that of 1949, with annual average growth rates of 12.4% and 11.9%, respectively; and volume doubling occurred in less than 7years (Wang, Chen 2010). Up to the end of 2008, the accumulative total amount of installed capacity of wind power is 12.15 GW. Fast development took place since 2005, when the government enacted its landmark national Renewable Energy Law. Installed capacity grew by over 106% in 2006, 127% in 2007, and 105% in 2008, respectively (Shi 2009).

In the solar energy field, development situations between thermal and photovoltaics are quite different. China's solar thermal industry has developed rapidly with a good future. In 2007, the sales of solar water heaters reached 12 million square meters in China. The industrial output was more than 13 billion RMB; in 2008, the total collector area of solar water heaters was about 1.3 million square meters and the annual product capacity was 3 billion square meters, increase rate was 20 % to 30% each year (Zhong et al. 2011). The Chinese living in areas with sufficient solar resources prefer using solar water heaters due to the nearly zero expense after purchase. photovoltaic (PV) is another application of solar resources by converting solar energy to electricity directly.

In PV sector, China also looks like quite powerful with rapidly growing speed on capacity of solar PV cells and modules production. During the past five years, world photovoltaic industry has an average growth rate of 49.5% , while Chinese photovoltaic industry has a fast pace of growth at an annual rate of 400% (Yan et al. 2009). In 2007 China has become the largest manufacturer and its production accounted to35% in the world PV cells production , while Japan was at the second place with a portion of 27% followed by Germany with a portion of 25% (Liu et al. 2010). However, unlike the fast growth in manufacturing area and widely application of solar water heater, installation of solar PV in China has not increased accordingly. China's domestic PV market grew by about 10 MW in 2006, just a fraction of the 370 MW produced by China's solar PV manufacturing industry, whose output was thus virtually all exported (Li 2008).

There are several puzzling issues in the Chinese PV industry. The first is the large gap between the manufacturing capacity of Chinese PV firms and application in domestic markets, which make people doubt whether the Chinese solar PV industry is as sunny as it looks. The second is the importance of the early and later technological innovation pattern of Chinese PV industry to understand its development path. These have been the obstacles to future development of Chinese PV industry. Answerers to these puzzles would be significant for the Chinese PV industry, and market cultivation, and further to mitigate climate change and other environmental problems without hindering economic growth. Moreover that promoting deployment PV systems could create more jobs and result in contributing to local and national economy. In the world on the supply side PV module shipments have been forecast to increase by a factor of 40 by 2025 and more than 3.2 million jobs may be created along the PV value chain (N. Marigo et al. 2008). It can be estimated that it would create more job in China due to its great potential for PV installation. Since solar PV industry contributes to national economy besides mitigating energy crisis and environmental problems, the research project is of paticular importance.

1.3 PV Technology and Manufacturing

Before delving deep into the research questions, a basic knowledge of PV technology is instrumental. It is helpful to understand the achievements and challenges of the current technologies, and in further help understand the industry and the process of innovation

1.3.1 The Photovoltaic (PV) Effect

The PV effect is defined as the ”generation of electromotive forces as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by use of the photovoltaic effect are called solar cells" (Sayigh 1977:263).

Photovoltaics encompass the entire technology of using solar cells or PV cells that absorb sunlight and transform it directly and continuously into electricity. All such processes take place without pollution, noiselessly and any moving parts (although some PV systems have sun trackers with moving parts). Apparently solar cells are the most important as well as fundamental parts in the PV system to generate electricity.

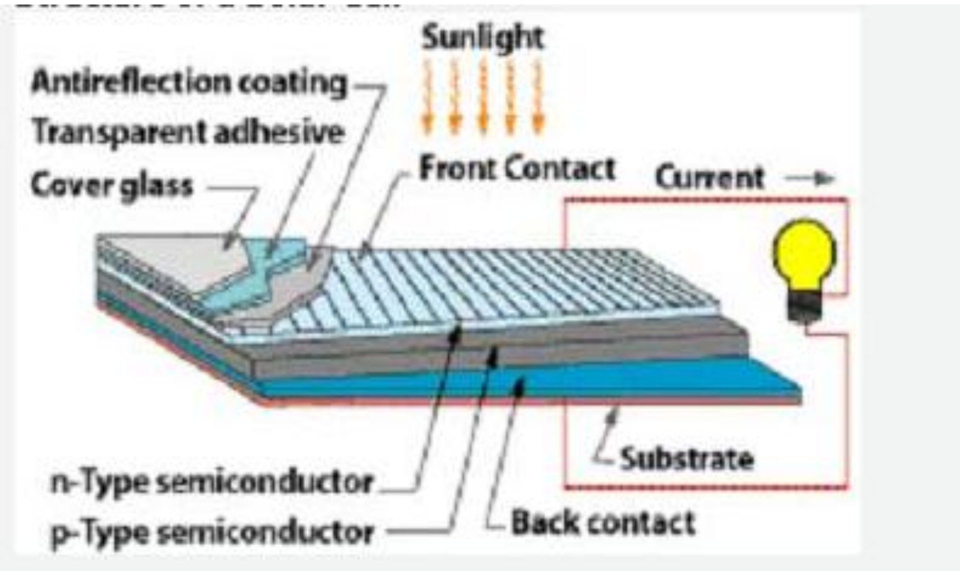


Figure 1. Illustration of PV effect

Source: Kennith 1984

Figure 1 illustrates the basic structure of a simply solar cell. The top layers encountered by sunlight are purposely transparent. The outermost layer, labeled cover glass in Figure 1, encapsulates the structure to protect it from the environment, keeping out water, water vapor and gaseous pollutants, which would otherwise corrode a cell during its extensive outdoor use. The cover glass is often hardened (tempered) to protect the cell from hail or wind damage.

After sunlight passes through the cover glass and the transparent adhesive that holds the cover glass to the cell, it encounters something called an antireflective (AR) coating, a transparent layer designed to reduce the amount of reflected sunlight.

The next layer (the striped surface in Figure 1) is called the front contact. It is a contact-- much like the plug in a wall socket--between the solar cell and an external current produced by the cell. It is often made of a metal such as aluminum or silver.

Light-generated current flows out of the cell through its entire top surface. And it is therefore important that the top contact reach everywhere on the cell.

The cell's bottom layer is called the back contact. Unlike the top contact, it can be a sheet of metal since it is not in the path of any sunlight. Electric current flows vertically through the cell to the bottom contact. The back and front contacts are necessary bridges for an external circuit.

The middle layers between the two contacts are the critical components. They are the guts of the cell, shown as n-type (n stands for negative) and p-type (p stands for positive) in the figure. Sunlight is absorbed and electricity is generated in this layers. Described simply, the PV effect is as follows: Light, which is pure energy, enters a PV cells and imparts enough energy to some electrons (negatively charged atomic particles) to free them (Kenneth 1984: 10). Basically speaking, the process is pretty simply. Light comes in; and electricity comes out.

There are two major families of PV generators: On-grid system, the electricity produced by which is fed into the collective grid; Off-grid system, intended to power certain functions on the spot, either without another energy source or with a complementary energy source, in which case they are described as hybrid systems. Or Solar PV system could be divided into small-scale PV system, large-scale PV power station and Building Integrated PV system (BIPV). The first one is mainly for family or application in remote area where there is no access to state grid, which are mostly off-grid systems; the second type is usually on-grid system built in deserts to transfer large amount of electricity to the grid. BIPV is usually applied in cities to solve the high energy consumption problems in buildings.

1.3.2 Silicon preparation

In a current high-volume module production plant single crystalline silicon module costs are divided between silicon wafer manufacture (silicon material costs, crystal growth, and slicing) at 60%, cell fabrication at 15%, and module fabrication at 25% (Ghannam et al. 1997); and module costs typically constitute 40-60% of total PV system costs (Harmon 2000). When we talk about PV industry, we mean the industry value chain to produce solar cells and modules, which starts with silicon production.

The basic constituent of sand, silicon exists in large quantities in nature in its oxidized form, since it is the basic constituent of sand, in the form of silica. The supply of silicon is practically endless for 60% of the earth's crust is sand, for the major part, quartzite or silicon dioxide (SiO_2) (Markvart, 2000). However this does not mean that silicon used in solar sector is easy to produce. In fact it was considered as bottleneck of the development of solar PV industry. For being a useful semiconductor material, silicon must be highly purified. For solar cells, the silicon must be 99.9999 percent pure (often referred to as "six nines" or 6N pure). The silicon grade used in electronics is even more pure, typically 9N to 11N (Flynn, Bradford 2006).

To make pure silicon, and in the form of crystallized quartz is refined by a reduction process by carbon in an arc electric furnace. The Siemens process is usually used to obtain material sufficiently pure to manufacture electronic or solar components.

Silicon used in solar cells has historically come from off-spec and waste silicon, produced either during the polysilicon purification process or during ingot and wafer production for semiconductor production. With the increasing demand for polysilicon in solar sector, innovative technologies such as FBR process and Vapor-to-Liquid Depostion (VLD) have been experimented in order to produce suitable product aiming to solar use at a low cost in an improved way.

1.3.3 Silicon Wafers Manufacture

Before manufacturing silicon wafer, purified silicon need to be shaped into a form that can be sliced with a wire saw. The shape can be an ingot, block, ribbon, or sheet. The product can also be monocrystalline (single crystal) or multicrystalline (polycrystalline). The Czochralski (CZ) and float zone methods produce monocrystalline ingots, while directional solidification/ casting, ribbon, and sheet techniques produce multicrystalline structures.

An important issue that should be paid attention to is the significant amount of waste during slicing process.

1.3.4 From Cells to PV Modules

After silicon wafers are sliced, they must undergo a couple of processes in solar cell manufacture. This is the last step of the production process. A cell is essentially a low-voltage, high-current device with a typical open-circuit voltage of around 0.5V, far lower than the operating voltage of most electrical loads and systems (Lynn 2010). Individual solar cells are hardly ever used on their own. To get higher voltages, solar cells are usually connected in series to achieve higher demanded voltages, which is also called “strings” of solar cells. Because these strings are very fragile, they are usually encapsulated in a soft plastic and glass sandwich creating which is called “solar module” or “PV module.” (Krauter 2006). Modules could be designed and made into different size and scale to meet the end users’s demands.

1.4 Natural Conditions

As one of the largest countries in the world, China has abundant solar resources. According to the China Meteorological Administration (CMA), Centre for Wind and Solar Energy Resources Assessment, the total reserves of solar resources are 1.47X108 billion kWh per year, equivalent to 24 000 tons of standard coal. Clearly the efficient exploration of solar resources could contribute a lot to carbon emission reduction and dynamics of energy consumption structure.

However due to geography, solar resources vary in different areas (See Figure 2). And it could be classified into five levels[1] by their annual average solar reserves.

[1] The lightest two categories are regardes as one in the following text due to the small amount of solar resources reserves.

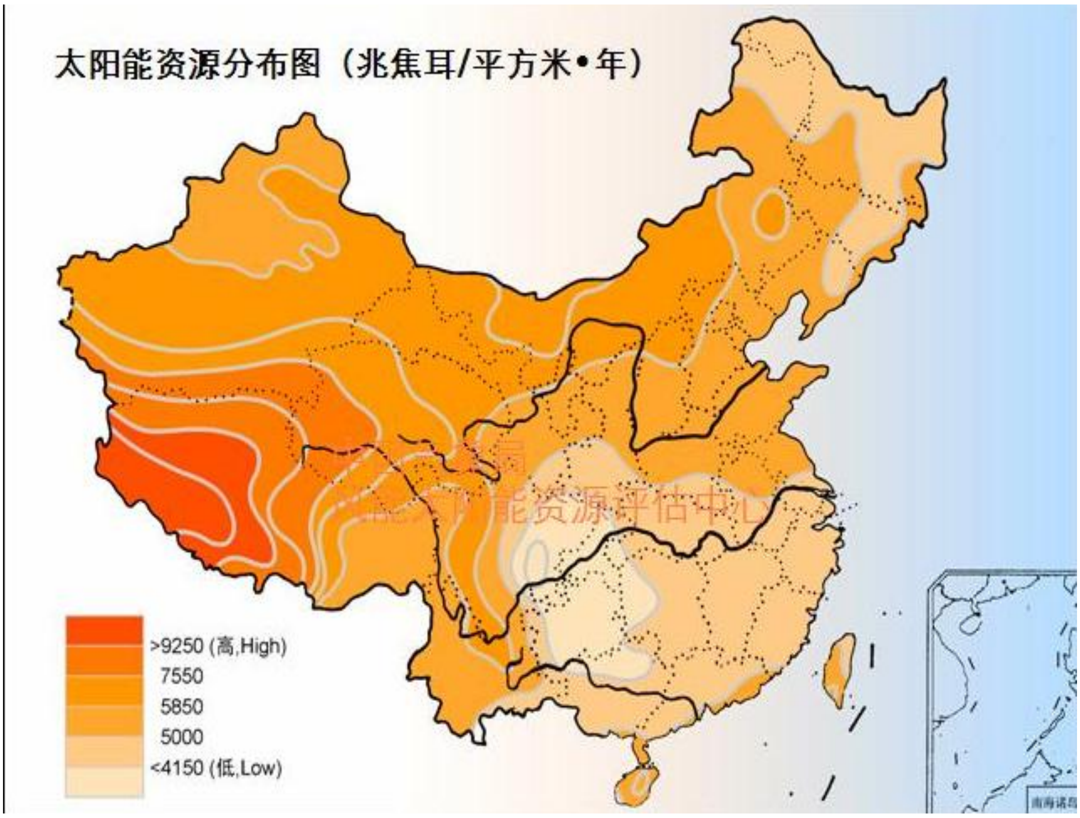


Figure 2. Distribution of Solar Resources in China

Source: From the Centre for Wind and Solar Energy Resources Assessment, the China Meteorological Administration

The first zone has the most abundant area with an average of 3200-3300 annual hours of sunshine and annual solar radiation per square meter of about 6680-8400 MJ, equivalent to the heat generated by burning 225-285 kg of standard coal. This area includes mainly the northern part of Ningxia province, the northern part of Gansu province, the southeast of Xinjiang province, the western of Qinghai province and western Tibet. Western Tibet area is especially rich with solar resources, with an average of about 2900-3400 annual hours of sunshine and with average solar radiation reaching 7000-8000 MJ per square meter per year. It is in the second position on the list of areas with rich solar resources, just after the Sahara Desert.

The second zone with an average of 3000-3200 annual hours of sunshine is located in the northwest of Hebei province, the northern part of Shanxi province, the southern part of Neimenggu province, the southern part of Ningxia province, inner area of Gansu province, the eastern Qinghai province, the southeast Tibet area and the southern of Xinjiang province. Total solar radiation is about 5852-6680 MJ per square every year.

The third zone includes the southeast parts of Shandong province, Henan province, Hebei province, Gansu province, south Shanxi province, north Xinjiang province, Jilin province, Liaoning Province, Yunnan province, the northern of Shanxi Province, the southern of Guangdong province, the southern of Fujian province, the northern of Anhui and Jiangsu province, Tianjin, Beijing and the western of Taiwan. Average sunshine hours are 2200-3000 every year and solar radiation is 5016-5852 MJ per square meter per year.

The fourth zone is less abundant area with an average of annual sunshine of 1400-2200 hours and the radiation in total is around 5000MJ per square meter per year. This catalogue covers areas of Hunan province, Hubei province, Guangxi province, Jiangxi province, Zhejiang province, the northern part of Fujian province and Guangdong province, the southern part of Shanxi province, Jiangsu province, Anhui province, Heilongjiang province and northeast of Taiwan.

The fifth and last zones are the least abundant regions in China including Sichuan province, Guizhou Province and Chongqin. Average sunshine is about 1000-1400 hours per year and annual radiation of each square meter is about 3344-4190 in average. (See Table 1).

Catalogue	Locations	Annual Sunshine Hours (h)	Annual Radiation(MJ/ ㎡)

1	Western Tibet, Southeast Xinjiang, Western Qinghai, Southern Gansu	2800-3300	6680-8400
2	Southeast Tibet, Southern Xinjiang, East Qinghai, Southern Ningxia, Inner Gansu, Neimenggu, Northern Shanxi, Northwest Hebei	3000-3200	5852-6680
3	Northern Xinjiang, Southeast Gansu, Southern Shanxi, Northern Shaanxi, Southest Hebei, Shandong, Henan, Jilin, Liaoning, Yunnan, Southern Guangdong, Southern Fujian, Northern Jiangsu, Northern Anhui	2200-3000	5016-5852
4	Hunan, Guangxi, Jiangxi, Zhejiang, Hubei, Northern Fujian, Northern Guangdong, Southern Shaanxi, Southern Jiangsu, Southern Anhui, Heilongjiang	1400-2200	4190-5016
5	Sichuan, Guizhou	1000-1400	3344-4190

Table 1. Solar Resources in Different Areas in China

Source: From the Centre for Wind and Solar Energy Resources Assessment, the China Meteorological Administration

Generally speaking the first three zones have abundant solar resources. Figure 2 shows that they are located mainly in the west of China, which is a less developed area with a low population density and poor economy. In China the number of Chinese households without access to grid electricity now or in the foreseeable future ranges between 9 million and 22 million. The majority of these are located in regions with abundant solar energy resources and could therefore be promoted as effective development (S. Ling et al. 2002). Given these aspects, western China is capable of deploying PV technologies andeastablishing renewable energies to improve the local economy and local people's living standard. However, in less developed regions, economical and technological conditions are not favorable for expanding and deploying the technology. Preferential policies, financial supports from the national government and international organizations as well as technological assistance are necessary to promote PV deployment in these areas. Another factor that complicates the deployment of PV technology is the diversity in natural resources and economic conditions, which creates huge differences between different areas. It is important to understand the complexity of the context when examining the TIS of the Chinese PV industry.

1.5 Thesis Structure

Before the main analysis, Chapter 2 and Chapter 3 present the study's theoretical approach and methodogy respectively. Chapter 2 offers a comparative presentation of innovation theories from three perspectives; and explains why the TIS approach is chosen. Chapter 3 first describes the rationale for choosing qualitative studies, and the strategies used in later part to obtain both first- and second- hand data for further analysis.

The core analysis starts in Chapter 4, including a presentation of situations of the formative stage as well as its characteristics. Last part of this chapter is analysis of technological innovation system at formative phase by figuring out which functions were served.

Chapter 5 discusses the achievements in PV sector in past ten year, the rapid growth stage and the industry's current status. It then maps the TIS in rapid growth stage to analyze functions served in this stage to explain the performance of Chinse PV industry.

Finally the conclusion part presents a short summay of the formative stage and the rapid growth stage, and comparison between the two phases followed by policy implication, limitations and directions for further study.

2. Theoretical Approach

To answer the research questions raised chapter 1, an appropriate theory is necessary, determining not only what data should be collected during the fieldwork but also how they can be analyzed. This chapter has, three main sections. The first covers the significance and definition of innovation, the second presents why the system approach is most suitable for innovation studies here, and the last section introduces innovation system approaches from current perspectives, with a discussion on technological innovation systems (TISs).

2.1 Innovation

Innovation is important to the economy: It plays a critical role "in nurturing the economy, in enhancing and sustaining the high performance of firms, in building industrial competitiveness, in improving the standard of living, and in creating a better quality of life" (Gopalakrishnan and Damanpour 1996:16). It is also of significance to firms because "innovation is widely considered as the life blood of corporate survival and growth" (Zahra and Covin 1994:183). Innovation is conceptualized in many different ways, but all share a common aspect. Plessis (2007:21) and Anahita and Baregheh (2009:1326) define innovation as follows

> Innovation as the creation of new knowledge and ideas to facilitate new business outcomes, aimed at improving internal business processes and structures and to create market driven products and services.

This definition links innovation closely to business, which can also be regarded as the distinction between invention and innovation: Invention indicates "the first occurrence of an idea for a new product or process," while innovation refers to "the first attempt to carry it out into practice" (Fagerberg 2005:4). Robert

(2007:36) simply differentiates between innovation and invention by the equation Innovation = Invention + Exploration. The author describes invention as a "process that covers all efforts aiming at creating new ideas and getting them to work," and exploration as a "process that includes all stage of commercial development, application and transfer" (Robert 2007:36). Invention and innovation are thus linked, but there is still a gap between them, reflecting efforts to make new ideas practical.

Innovations can be classified by how radically they change the current technology level. From this perspective, three kinds of innovation are characterized: Incremental innovation usually refers to upgrades to existing technology; disruptive innovation indicates changes in how things are done but not changes to the overall system; finally radical innovation involves wholly new technology, new operations, and new organizational forms (Smith 2009). Disruptive and radical innovations appear to be more significant, since they can bring about important changes, which is why Schumpeter focuses on these two kinds of innovation(Fagerberg 2005). Smith (2009) also argues that radical innovations are required to generate low- or zero-emission energy technologies to simuitaneously mitigate climate change issues and sustain economic growth. However, incremental innovations can also contribute to economic and social change, and even radical innovations are based on cumulative incremental innovations (Fagerberg 2005, Lundvall et al. 1992). Since it is difficult to suddenly generate radical or disruptive innovation without the preparation of various incremental innovations, we argue that incremental innovation is as important as disruptive and radical innovations.

Specific contexts should be considered in the Chinese PV industry. The PV technology was derived from that of developed countries, such as Germany, Japan, and the United States for a long time, during which China was not even involved in the indusstry. When China started its own PV industry, it relied largely on importing equipment and materials from abroad a process sometimes called technology transfer. Introduction of a technology within a given context likely leads to adaptation which can imply incremental innovation or/and changes in social or economic or institutional aspects (Fagerberg 2005). The innovations discussed in this thesis are likely to be incremental ones that happened in and after the technology transfer. This thesis studied these incremental innovations in the Chinese PV industry by analyzing the emergence, development, and influence of the TIS.

2.2 Systems and Innovation Systems

2.2.1 Innovation and Systems

Given the gap between innovation and invention, innovation would simply not take place without the bridging. Elements of knowledge acquisition, financial support, market information, preferential policies, legitimacy and standards (Fagerberg 2005). These aspects indicate the different actors involved in the innovation process,such as firms, governmental departments, and research institutions, and their interactions. Scholars thus realize that technological development cannot be studied as an isolated phenomenon.

Increasing demand has stimulated the emergence of an innovation system approach, which is more specific and innovation-oriented to study technology as a part of a larger system. The actors, institutions, and networks involved and their relationships are thus emphasized and viewed as important system components. This perspective makes it natural to study innovation in a context consisting of different actors whose interactions can influence the results of innovation. De Ven et al. (1999) argue that collective achievement leads to innovation, requiring the efforts of numerous actors in both the public and private sectors, and that the social system of innovation captures the features of collective achievement.

Webster's Collegiate Dictionary defines a system as "a set or arrangement of things so related or connected as to form a unity or organic whole" (1999:1453). According to Ingelstam(2002:19), Edquist(2005:187) also paraphrases common explanations of system in everyday language, as well as in scientific contexts:

> i. A system consists of two kinds of constituents: There are, first, some kinds of components and, second, relations among them. The components and relations should form a coherent whole (which has properties different from the properties of the constituents).
>
> ii. The system has a function, i.e. it is performing or achieving something.
>
> iii. It must be possible to discriminate between the system and the rest of the world; i.e. it must be possible to identify the boundaries of the system. If we, for example, want to make empirical studies of specific systems, we must, of course, know their extent.

In sum systems are identified by such characteristics as their boundaries, their different types of components, and the interactions between these components which in turn achieve certain results together. These characteristics fulfill the requirements of actor interactions for achieving innovation, which makes it natural to apply a system perspective when examining innovation phenomena.

There are several definitions of innovation systems in the literature, all with the same scope and derived from one of the first definitions of systems of innovation : networks of institutions in public or private sectors to initiate, import, modify and diffuse new technology (Freeman 1987). Innovation systems are composed of a set of actors and institutions and the relationships between these that develop, diffuse, and use innovations (Carlsson and Stankiewicz, 1991, Edquist, 2005, Malerba, 2002). Edquist (2004:190) states that “the main function — or the ‘overall function’ of an innovation system—is to pursue innovation processes, i.e., to develop, diffuse and use innovations.”

The adoption innovation systems requires focusing on innovation and the learning process, distinguishing this study’s approaches from others that regard technological change and innovations as exogenous (Edquist 2005). With this focus, the innovation system approach usually has historical and evolutionary perspectives on the development of innovations over time. In addition, a holistic and interdisciplinary perspective is adopted allowing for the analysis of the involvement of organizational, social, political and economic factors. At the same time, the interactions between factors capture non-linear features of innovation processes.

The strengths of this innovation system approach (Edquist 2005) make it appropriate to use in studying the Chinese PV industry. With the innovation system approach, the actors involved in the innovations of the PV sector are examined through a historical and holistic perspective to explore their different roles during the past decades and their mutual interactions. The characteristics of innovation in the Chinese PV sector can thus be analyzed, and key lessons learned for future development.

2.2.2 Multiple-perspective of the Innovation System

Different innovations systems can be assessed and compared with regard to the functions they fulfill (Bergek et al. 2005, Hekkert et al. 2007, Johnson 2001, Hekkert et al. 2007). Sub-theories of innovation systems are generated according to the different aspects of the innovation systems in question.

Innovation systems are identified more specifically by their different emphasis on different system aspects.

Three perspectives—national, sectoral, and regional— can be regarded as variants of a single generic system of innovation approach (Edquist 1997b:3, 11-12). The first concept introduced in the literature was the national innovation system (NIS) rooted in evolutionary economic theories on socio-technical change (Lundvall 1992, Markard, and Truffer 2008, Nelson 1993-). Regional system and sectoral systems of innovation were later proposed on the same theoretical basis as complementary perspectives (Asheim and Gertler 2005, Carlsson, 2007, Carlsson et al. 2002, Chang and Chen 2004, Edquist 1997).

Several definitions exist for the NIS. According to Nelson(1993: 4), an NIS ‘‘is a set of institutions whose interactions determine the innovative performance of national firms,’’ whereas for Lundvall(1992: 2)it ‘‘is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge.’’ Both authors note institutions, or elements, as components of an innovation system as well as their mutual interactions. These institutions, or elements, can consist of firms, public laboratories, and universities, as well as financial institutions, educational systems, government regulatory bodies, and so forth all interacting together (Breschi and Malerba 1997, Godin 2009).

According to Carlsson (2007), the NIS has dominated the innovation systems literature of the past 20 years, comprising about 50% of all publications.Its introduction brought about a new integrated, institutional and evolutionary way of thinking about innovation activity (Fromhold-Eisebit 2007).

By applying NIS, analysis is carried out at the national level. Components such as research and development (R&D) efforts, the quality of educational systems, university-industry collaborations, the government, the availability of venture capital, and the linkages between them are examined at the aggregate level (Carlsson et al. 2002, Hekkert et al. 2007). However when innovation systems are examined at the national level, because of the size, complexity, and number of components, the dynamics of innovations are difficult to map. As a result, most empirical NSI studies focus on the structure of innovation systems rather than their emergence and dynamics. (Hekkert et al. 2007, 2009).

Another approach is that of the sectoral innovation system (SIS) (Breschi and Malerba 1997, Malerba and Orsenigo 1990, 1993, 1995). The SIS is based on a sector or industry and usually defined asfollows(Breschi and Malerba 1997:131):

> A system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies; such a system of firms is related in two different ways: through processes of interaction and cooperation in artefact-technology development and through processes of competition and selection in innovative and market activities.

The latest definition of SIS is likely that of Malerba (2004:16) :

> The sectoral system of innovation and production is composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products.

Both definitions highlight products and firms, and the SIS can therefore include multiple technologies and overcome geographical boundaries. In the age of economic globalization, many firms operate and compete beyond the national level. It is quite common for firms in some industries to compete at the international level while their main materials and factories are domestic, and vice versa. The SIS offers better understanding of the structure and boundaries of a certain sector. For example, Coenen, and D ́ıaz L ́ope_(2010) argue that the emphasis of SIS on product_-groups-for example, automobiles, chemicals, and construction—provides a useful connection to NACE, the standard statistical classification of economic activities within the European Community. This facilitates the use of statistical data to coherently analyze sectoral innovation patterns.

A relatively new concept, the regional innovation system (RIS) first appeared in the early 1990s-, inspired by the NIS, both being based on a similar emphasis of the territoriality of innovation systems (Asheim and Gertler 2005). The RIS can be thought of as the institutional infrastructure supporting innovation within a region, highlighting the importance of governance between the national level and individual clusters, or the firm level (Asheim and Cooke 1999, Asheim and Gertler 2005). According to Cooke (2001), the difference between the NIS and the RIS lies in the different contexts in which innovations take place. The NIS works well under a well-established national institutional framework that grows incrementally to meet the needs for industry innovation, while the RIS is more suitable for new economies or industries in a more flexible environment with uncertain long-term stability.

2.3 The TIS and TIS in Practice

The TIS approach is another variant of the innovation system that focuses on different aspects of the innovation process from those in the NIS and SIS.

The TIS approach makes it possible to study the dynamics of a set of key processes in a specific technological field. There are many empirical applications of the TIS in renewable energy and other technologies, such as renewable energy technologies in Sweden (Johnson and Jacobsson 2001), wind turbines (Bergek and Jacobsson 2003), solar cells in Germany (Jacobsson et al. 2004, Jacobsson and Lauber 2006), and Swedish security sensors(Oltander and Vico 2005).

Although many studies employ the TIS or other innovation system approaches, studies on renewable energies and, more specifically, solar PV systems in China seldom involve the use of innovation systems. Huang and Wu (2004) conduct a study about renewable energy in Taiwan that applies the TIS framework to analyze the evolution of the solar PV industry in Taiwan. Marigo et al. (2008) adopt the NIS framework in the analysis of innovation systems of the PV industry in the United Kingdom and China by identifying different technological and institutional actors and their relations in each innovation system.

Carlsson and Stankiewicz’s(1991:111)definition of a technological system is frequently cited as a

> Network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks.

This suggests that the TIS approach is not limited to certain sectoral or geographical boundaries, which provides a more heterogeneous approach to studying a new technology applied in several sectors or internationally. For example, biotechnology is used in many industries, such as pharmaceuticals, food, and agriculture. By treating the technology as a common object, the TIS allows for a framework for studying the change of configuration of actors, networks, and institutions over time (Carlsson 1997).

After the pioneering studies of Carlsson, the emphasis turned to the dynamic analysis of TISs, which has received considerable impetus recently through its explicit focus on the functions, activities, and progress taking place within systems of innovation (Hekkert et al., 2007; Bergek et al., 2008). Bergek et al. 2008) develop a functional approach to innovation system dynamics by applying a practical scheme for analysis (see Figure 3). These practical guidelines allow researchers and policy makers to analyze certain innovation systems to identify key policy issues and set policy goals. The practical guidelines suggest both a systematic approach and a framework. With the former, it is possible to describe, analyze, and assess an innovation system, while the latter captures an innovation system's structural characteristics and dynamics. Key processes are denoted functions, and these have an impact on the development and diffusion of technology and thus the performance of the system (Bergek et al., 2008).

Such function-oriented characteristics can be regarded as distinct from those of other innovation system approaches. This functional perspective on innovation systems emphasizes the dynamics of the key processes of innovation, as well as the importance of the system's achievements and operations compared to its composition or structure (Bergek et al. 2005). Jacobsson and Johnson (2000) state that a TIS can be described and studied in terms of its "functional pattern" examining how these functions are fulfilled or interact and by which dynamics each function can be examined, as well as their mutual interactions.

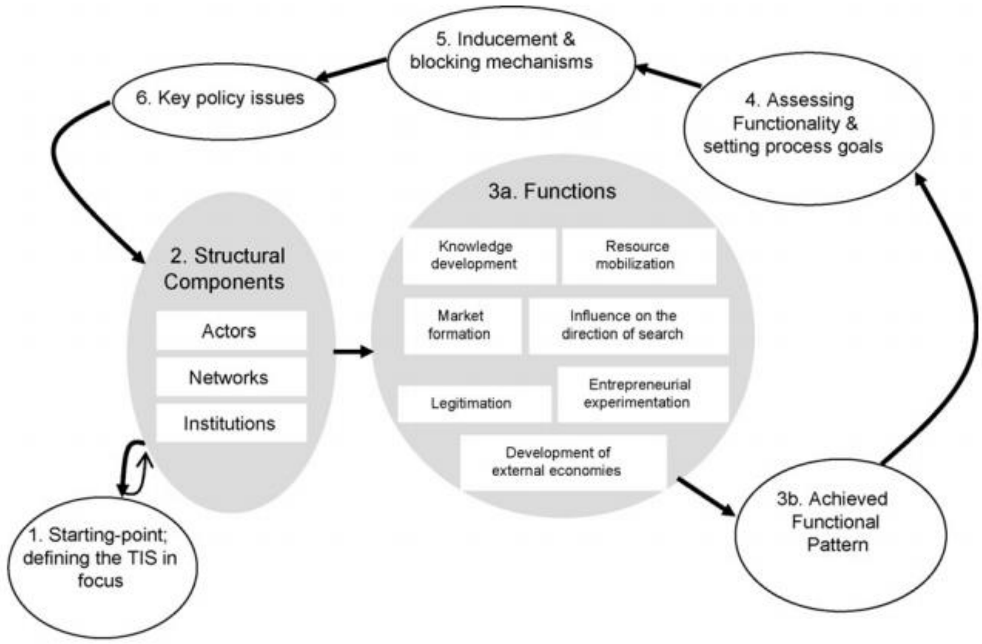


Figure 3. Scheme for TIS analysis.

Source:Bergek et al. 2008, Oltander and Perez Vico 2005.

As shown in Figure 3, seven functions are included (Bergek et al. 2008).

1. Knowledge development and diffusion: Knowledge is considered a central part of an innovation system and captures the depth and breadth of the knowledge base of a TIS. An innovation system can be defined in terms of knowledge generation, diffusion, and utilization (Carlsson and Stankiewicz 1995). Knowledge development can also be regarded as the system's overall goal. Knowledge can be classified into at least three components (Garud 1997:84): *know-why,* "representing an understanding of the principles underlying the construction of each component and the interactions between them"; *know-how,* "representing an understanding of procedures required to manufacture each component and an understanding of how the components should be put together to perform as a system"; and *know-what,* "representing an understanding of the specific system configurations that different customer groups may want and the differences uses they may put these systems to."

Each of these three components and their synchronization are important to manage knowledge, diffuse knowledge, and generate new knowledge (Dougherty 1992b, Garud 1997, Senge 1990). There are three ways to achieve the three components of knowledge: learning by studying, learning by doing, and learning by using (Garud 1997). To be specific, scientific management can serve as a basis for the creation of knowledge (Zuboff 1984), R&D projects can establish the foundations for the commercial application of knowledge (Comroe and Dripps 1976), customer feedback can improve current products, imitation can learn and diffuse advanced technology, and so on. The various actors then work as indicators for this function, as in the number of R&D projects, the number of professors, the number of patents, and the number of research institutes.

In the case of computer numerical controlled (CNC) machine tools in Korea (Carlsson 2003), R&D cooperation between domestic builders has helped diffuse and generate knowledge. In 1988, through Korea Industrial Electronics, firms established a joint venture for joint R&D projects financed by five domestic builders and the government. The joint venture activity had a clear commercial focus of developing CNC control technology. Companies improved their ability to fully adopt and assimilate the CNC technology within the technological system, and the R&D partnership between Hyundai Precision, Turbo-Tek, and Namsun enabled each firm to strengthen its own technological or strategic weaknesses through participation. Because of the three firms' cooperation, a new CNC lathe, the HiT-8EX, was developed.

2. Influence on the direction of search: This function involves elements that have an impact on how firms and other organizations within and outside the system search with regard to applications, markets, business models, and so on. These elements include visions, expectations, and beliefs in growth potential and actors' perceptions of the relevance of different types and

sources of knowledge, for a combined effect. Technological choice and market choice are both included in the function (Johnson and Jacobsson 2004). This function indicates to push firms or organizations to enter the sector either in a technological field or market field by incentives and/or pressures.

An illustrative example is the case of solar cells in Germany (Jacobsson et al. 2004). During the period of "science-based experimentation," major funds were invested in cell and module development, as well as thin-film technologies. Amorphous silicon (a-Si) was regarded as the thin-film technology that would eventually replace crystalline cells. Around 1980, the former Messerschmidt-Boölkow-Blohm (MBB) aerospace company —began a-Si experimentation. At the end of the 1980s, they built a dedicated plant in the hope that a-Si would become a base material for cost-effective solar modules.

3. Entrepreneurial experimentation: Uncertainty is always connected with risk in a TIS, in both the early and later stages. This is due to not only lack of information but also techno-economic problems and the lack of precise predictions about the results of certain actions (Dosi 1988). Entrepreneurial experimentation can be a main factor in reducing uncertainty by encouraging new entrants to conduct trials in new technologies and applications. Some trials will fail, while other will succeed, and a social learning process is thus learned, which is important to innovation generation. Whether there are new entrants or new applications, their numbers and other characteristics should be examined as indicators in this function.

The idea of the standardization and building of the Nordic mobile telephone system (NMT) was first raised by the Swedish telecommunications administration (Lehenkari and Miettinen 2002). The NMT group was formed when other Nordic countries became involved. The costs and feasibility of the different technical solutions were compared and, according to each country's special areas of knowledge, the planning and development tasks were collectively distributed between the various countries' telecommunications administrations. Technical solutions were tested, and risk was mitigated by distributing different development tasks to different countries according to their capabilities.

4. Market formation: Market formation is the process a new technology undergoes from a nursing market to a bridging market and then to a mass market. Markets are necessary for firms to make investments of various types to identify and reach new customers. They are also important for testing technology and products. Huo et al. (2010) argue that the growth of the market scale increases domestic PV innovation, and thus the market incentive can promote both the diffusion and innovation of PV technology. Markets of emerging technology are usually underdeveloped, requiring incentives to push and promote their development. In this function, not only should market development be examined, but also the incentives driving it.

   In the case of solar cell development in Germany (Jacobsson et al. 2004) in the early 1990s, the German market was still small. A series of lobbying activities were put forward by the Foörderverein Solarenergie and Eurosolar. Various preferential policies and regulations were generated to cultivate market development since 1984, giving rise to the concept of a "cost covering feed-in-law." In 1998 a market formation program called for by firms and other organizations was decided upon and started in January 1999.

5. Legitimation: Legitimation is a prerequisite to developing a new technology, and sound legitimation is regarded as a sign of a mature technology and industry, since it is a matter of social acceptance and compliance. If the whole market is in disorder, without standards, relevant regulations, or a quality supervision system, this would greatly reduce the enthusiasm of enterprises and innovation. Two factors are usually analyzed

when mapping the legitimation function: legitimation in the eyes of the various involved actors and stakeholders, and activities within the system that impact increasing legitimation.

The comparative studies of the German, Dutch, and Swedish wind turbine industries (Johnson and Jacobsson 2003) regard legitimacy as a key concept to explain why the German and Dutch innovation systems had superior functionality duing the experimentation phase. In the 1980s there was already a political consensus that wind turbines should be encouraged. It was thus legitimate for private capital to exploit wind turbine technology, facilitating firms to respond to various stimuli by diversifying into wind turbines or starting a new firm. However, similar legitimacy was lacking in Sweden, and few individuals and firms saw the same stimuli as their Germany and Dutch competitors. Legitimacy played an important role here.

Resource mobilization: Resources including but not limited to capital volume are fundamental in a TIS. To some extent, abundant resources can reduce the uncertainty and risk associated with a new technology. Such resources include human capital a well. Moreover, resources are important for other functions to evolve.

For example, venture capital (VC) played an important role in the start-up stages of Silicon Valley (Hellmann and Puri 2002), providing capital for new firms to develop and/or existing firms to expand their opportunities.

6. Development of positive externalities: Positive external economies are key factors in the formation and growth of a TIS. In the formative stage, positive external economies are essential for attracting initial investments and resources. They are also critical for growth in later stages. Pooled labor markets, goods, and service providers, among other, are indicators in this function. The development of positive externalities can include the effects of entrepreneurial experimentation or the entry of new firms on other systemic

components and functions. This function does not work independently, however, and straightens the other six functions to facilitate development of the system.

These functions are not independent of each another, and changes in one function can lead to changes in the others (Huang and Wu 2007). The links between functions can be circular, reflecting the influences between the functions (Johnson and Jacobsson 2004). For example, when a market is formed, more resources can be committed to this field for profits, which in turn can influence the direction of search. Greater numbers of participants entering the sector indicate more resources flowing to the system, which serves the function of both entrepreneurial experimentation and resource mobilization.

The development of positive externalities enhances, in turn, the above two functions. As a result, the framework provides an effective means of analyzing the dynamics of a technological system by examining its functions and the interactions between them, in accordance with the definition of a system, including the actors and their mutual interactions. It is also important to study network formation and institutional attention to determine the evolution of the functional pattern of a TIS and its driving incentives, and this is also addressed by the framework.

Compared with the NIS or SIS approach, which both take a broader perspective, the emphasis of the TIS approach on the institutions and networks of agents involved in the generation, diffusion, and utilization of a certain technology fits best in the analysis of specific aspects of interest in technological change (Hekkert and Negro 2009). Since the SIS sets boundaries on the basis of existing products, it is not very appropriate in the case of an emerging technology, while the TIS approach appears better equipped to deal with such a case (Coenen 2009). Even though PV technology has been developed for decades and has been deployed since a while, the Chinese PV industry is still emerging and needs innovation and further development. The focus of the TIS on the technology base is consistent with the Chinese PV industry. As stated before, the TIS approach has been widely applied to study renewable technologies, but the Chinese case is missing.

This thesis thus employs the TIS approach to identify the functions of the PV innovation system in China and then determines which functions are weak and which have a stronger impact on the system. This study also examines the interactions and relations between these functions. Technological change in the solar cell industry manifests itself as a multi-spatial process, and market creation and the export of products are normally influenced by international dynamics, rendering the NIS inappropriate in this thesis.

3. Methodology

This chapter describes methods forming this study's research design to find answers to research questions, including the rationale for choosing them and the practical process of data collection and analysis.

3.1 A Flexible Qualitative Study

3.1.1 Qualitative Studies

A research design is "the logic that links the data to be collected (and the conclusions to be drawn) to the initial questions of study" (Yin 2003:19). To answer the research questions raised here, a qualitative study is preferred in this study first is "because of the nature of the research question" (Creswell 1998:17). According to Creswell (1998), research questions that starts with a *how* and *what* make forays into the topic describe what is going on are probably appropriate for a qualitative study. The research questions raised in the introduction part comply with this standard, at least from the point of view that the questions start with *what* and *how*. From the perspective of content, the first part of analysis provides an overall picture of the Chinese PV industry at each phase by investigating its history and current situations.

Second, qualitative researchers study things "in their natural setting" (Richardson et al 1994:2), which means researchers must go out into the field to collect empirical data to understand a given research subject. In this way, one of the advantages of this method is obvious. Problems are better explained and understood within the original setting. China has always been regarded as a unique country due to its history and political system. In this case, it is therefore critical and necessary to comprehend Chinese PV industry in its "*natural setting*". Without a knowledge of the background, the research topic can not be fully explored.

Another reason for choosing a qualitative study is "the desire to step beyond the known, see the world and make discoveries that will contribute to the development of empirical knowledge" (Corbin and Strauss 2008:16). The researchers' role in the study is that of an active learner who tells a story from informants' view rather than as an expert who simply passes judgments (Creswell 1998). I have been interested in renewable energy which appears to be a promising solution for climate change problems. However I knew little when I started in this field. I consider myself as a student in fieldwork in which I tested my findings against previous literature reviews and obtained practical perspectives from informants.

The last but not least important reason for choosing a qualitative study concerns variables. Creswell (1998) mentions that Ragin (1987) summarizes a key difference between qualitative and quantitative studies. Quantitative researchers work with a few variables and many cases, whereas qualitative researchers rely on a few cases and many variables (Creswell 1998:15-16). When researchers have little control on the variables, a qualitative study is clearly preferred. In the field, I rarely had controls on the variables. I followed clues extracted from either literature or informants to collect data and then carries out interpretation and analysis.

3.1.2 Flexibility

Robson (2002) has stated in the book *Real World Research* that "the task of carrying out an enquiry is complicated by the fact that there is no overall consensus about how to conceptualize the doing of research" (Robson 2002:45).

It is apparently different people hold different opinions towards how to conduct a research for people with different personal and academic preferences from various disciplines. Robson also mentions two different models. In one model, the researcher knows exactly what he or she is going to do before and collect data as planned before starting the analysis; while the other one expects the research to "develop research design through interaction with whatever he or she is studying and has data collection and analysis intertwined" (Robson 2002:81). The latter one is referred as a flexible design in this book.

The characteristics of qualitative studies, such as the various variables determine the importance and necessity of flexibility in the study. Even if one knows exactly the kind of data to be collected, variables in fieldwork can make it difficult in access to ideal informants and documents. Flexibility then appears to be the only solution to the problem. Repeated revisits of all the aspects during the research are possible and allowe one to refine and modify the set of research questions or to change the intended sample to follow up interesting concepts, even review the purposes of the study (Robson 2002). Flexibility has enabled me to look back the materials I read, make some revisions, and integrate data I could have access to fulfill a research project.

In the beginning I was more interested in the applications of PV technology. I had planned to study certain application projects to explore what factors obstructed the development of the Chinese market and what experiences could be learned from existing projects to promote PV application. However I found very little materials on this topic. Reports about application are frequently just about the launch of projects without progress presentation and operation conditions after foundation. Attempts at phone contacts with several PV projects including one in Tibet were unsuccessful.

I then reviewed all the materials I had read till that point and regarded the subject from another angle.I shifted the sights to the PV industry in China as the research field because first it is in line with my interests as well, and data about firms are easier to have access to since they all have official websites in which not only could find a lot of information about them and also contact information as well. Other informants I have interviewed also suggested this direction and could contribute to this topic.

There is always an ideal way of carrying out an enquiry that forms in the researcher's mind before research starts. But in reality it may not be practical or feasible. This research project's features are thus its qualitative nature and flexibility.

3.2 Case Study

Case study as one of the traditions of qualitative inquiry is "a strategy for doing research in which involves an empirical investigations of a particular contemporary phenomenon within its real life context using multiple sources of evidence" (Yin 2003:15). There are two key features of case study extracted from the definition. The first one is to collect and deal with a wide range of data like documents, interviews and observation. The second one is to study the case under its real life context. "You would use the case study method because you deliberately wanted to cover contextual conditions-believing that they might be highly pertinent to your phenomenon of study" (Yin 2003: 13). The attention paid to context is important in representing cases objectively, and "minimize the chances of distorting meaning and/or misrepresenting intent" (Corbin and Strauss 2008:57).

It is important to study the solar PV sector as a case study since the contexts could not be ignored. The social, economic and institutional environment to some extent shapes the technology innovation system. And China’s unique political and economic systems features has influenced the TIS of Chinese PV sector. With attention to context, in-depth understanding is possible.

3.3 Data Collection

Data collection is the most basic and important part of the entire project. After deciding on the focus of the research and research strategy, researchers should think about the actual methods to collect data to fulfill the project. Generally there are two kinds of data to be analyzed in a study: first-hand data that are collected by our own investigation, and second-hand data that are gathered by other individuals or from other sources (Hug and McNeill 2008). Qualitative researchers typically employ the following methods for gathering information. They are participant observation, non-participant observation, field notes, reflexive journals, structured interview, iemi-structured Interview, unstructured interview, and analysis of documents and materials (Marshall et al. 1989). In the study, documents and archival records were reviewed for second-hand materials, while first-hand data were collected through interviews.

3.3.1 First-Hand Data

Many methods are available to collect first-hand data, such as interviews, observations and surveys. My project uses interviews as the primary approach to find out what people or firms in the Chinese PV industry are doing and thinking and causes and influence of their activities.

Yin (2003) classified interviews into three types: open-ended interviews in which key respondents are asked about facts, opinions about the facts and even propositions for further inquiry; focused interviews in which the researchers are more likely to follow a set of questions derived before; and a formal survey, which is more structured, with the questions designed in advance.

Open-ended interviews were employed to collect all kinds of information about the Chinese PV industry. I originally intended to interview people from the chosen companies, policy making departments, industry association, experts and non-governmental organizations. However it turned out to be difficult to interview the ideal informants. Some were reluctant to talk, while some did not reply emails or answer phone calls. Replies from companies were usually very official, directing me to check their websites for further information. But their websites were aim at current and potential consumers, which apparently are not appropriate for the study. Everything seemed in a dead end.

Later I was lucky to be introduced to Inga who works at World Wild Fund (WWF) Norway. Since WWF Norway and WWF China are cooperating on the project of *Low-carbon City Construction*[1], staff in WWF China who had working experience on PV development in China was introduced. Moreover, since Baoding, the location of the firm Yingli Solar, is a pilot city of the project, I was also introduced to Baoding government. I subsequently received a great deal of assistance from many kind people.

My fieldwork in China went from February to March 2011. During this period, I went to Beijing and Baoding to interview people from WWF China, the Baoding government and Yingli Solar. Some were conducted face to face, while others were over the telephone. These interviews gave me empirical information about

[1] This project was initiated by WWF China and involves cooperation among various organizations aiming to provide a city model with low GHG emission. It will be explained in detail in later part.

their cooperation on *Low Carbon City Project* and influence on solar firms located in Baoding. A friend introduced me to an inverters producer of family used PV systems for German market who enlightened me about the general real situation of the world and Chinese PV industry which was definitely helpful for further inquiry. I returned to Oslo in April, but the data collection did not stop along with it.

Another important data source is the Google Group called the Beijing Energy Network (BEN). BEN[1] is

A grassroots organization based in Beijing with a mission of promoting networking and collaboration in understanding and tackling China's energy and environmental challenges among individuals and organizations from diverse sectors such as government, finance, industry, media, advocacy, think tanks and academia.

The Google Group is used for online discussions and information sharing. Through BEN, I was able to get in touch with Richard Matsui, a partner at Honua Solutions, a solar consultancy based in Hawaii, and a manager from an Australian solar company doing business with Chinese solar companies, and obtained their opinions on Chinese PV industry. Later, I contacted with an editor from Energy Review, a magazine in China (through the group again) to discuss the latest status of Chinese PV industry. At the same time by keeping trace with all emails, I was able to follow the latest news in this field. I tried to get information and opinions from multiple perspectives. My analysis was based on materials collected in many ways including taped interviews(with the informants' permission) and a personal diary for recording my thoughts.

[1] The introduction of BEN is obtained from their website: http://greenleapforward.com/beijing-energy-network/

3.3.2 Second-hand Data

Second-hand data include reports, documents, papers and firm websites. According to Corbin and Strauss (2008), these could be used as primary data as well as to supplement interviews and observations. I used second-hand data mainly for two purposes. The first was to acquire as much information as possible to understand more about the topic, as well as derive better and more insightful questions for interviews. Besides, it is polite to show a familiarity with the topic during interviews which also helps gain acceptance making informant more likely to share their knowledge. The second was to supplement first-hand data to make the analysis more rigorous.

3.4 Data Analysis

Data analysis is another important process in the research. The first and most preferred data analysis strategy is to "follow the theoretical propositions that led to the case study" (Yin 2003:111). This involves the theory to some extent deciding what kind of data should be collected in case study originally. The most important goal of analyzing qualitative data is to determine the categories, relationships and assumptions that present the respondents' view of the world in general and on the topic in particular (McCracken, 1988). Due to the complexity of qualitative data, this is regarded as a very demanding task of the whole research project (Miles 1979).

To analyze data systematically, coding or categorization plays an important role since it involves allocating units of meaning to the descriptive or inferential information compiled during the study; and creating of categories or codes triggers the construction of a conceptual scheme that suits the data, which helps the researcher to ask the proper questions, to compare across data, to change or drop categories and to rank them in a hierarchical order (Dey 1993, Tehmina Basit 2003). In this case since the technology Innovation System consists of seven functions that have built up a conceptual scheme as well, coding is applied in the analysis. By categorizing the data by function into seven different groups, the effect of each function can be determined, including which functions are missing and which are very strong or extremely weak. Research questions then could be addressed.

3.5 Rigor

It is important to evaluate the rigor of the entire study in the end. Though it is difficult to evaluate interpretative data, this step cannot be omitted. Validity and generalization are usually considered as core standards for examining rigor. Science is concerned with rigor and if this concept is rejected, it will undermine the belief that qualitative research is a scientific process that has a valued contribution to make to the advancement of knowledge (Morse 1999; Tobin and Begley 2004).

In regard to evaluating rigor, since qualitative research is unlike quantitative research which is much easier to assess, Silverman (1993) has introduced a simple way to subject the evidence to every possible test. When the existence of certain evidence can not be refuted, then it is objective and reliable.

In this study, testing rigor appears to be more difficult since the data resources were very dynamic. I therefore tried to use multiple resources to construct convergent lines of inquiry. I also kept a record of the materials and tested them with both old and new data.

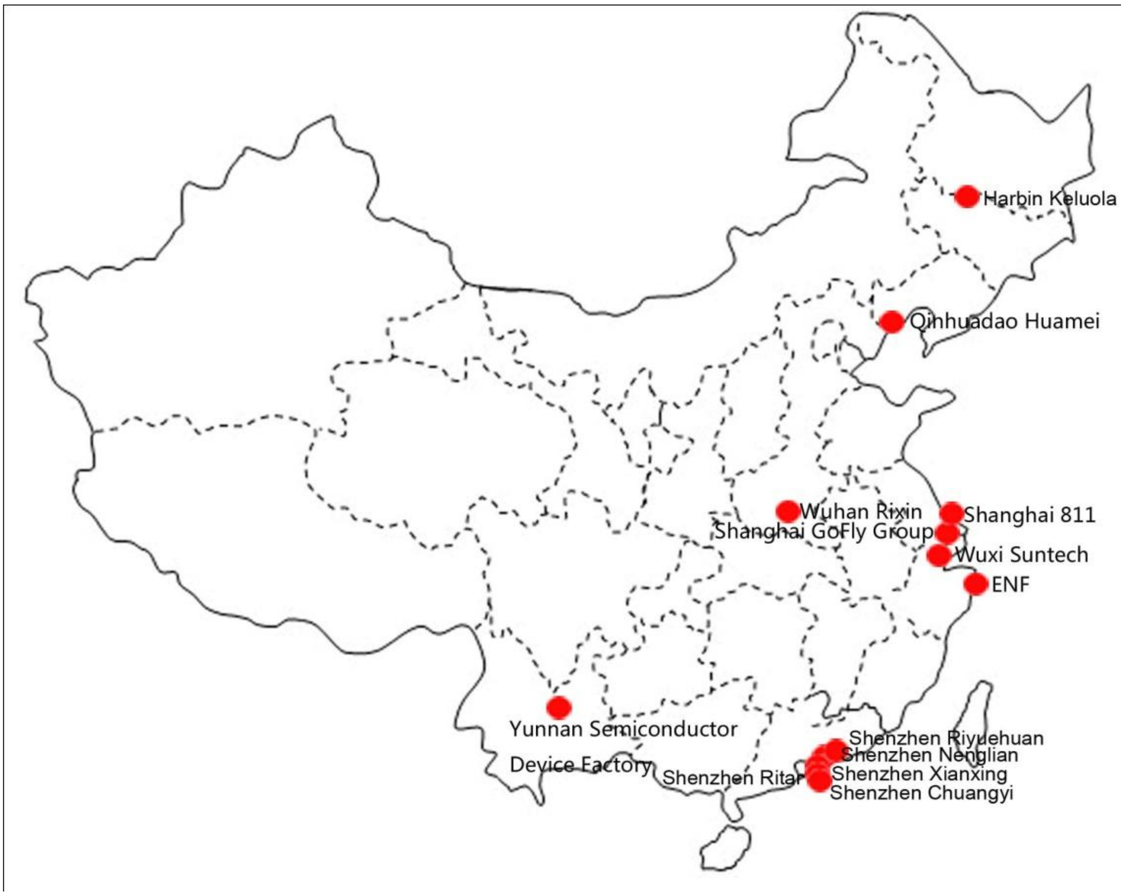
4. The Chinese PV Industry in the 1950s to 2002(Formative Stage)

To understand the development of the Chinese PV industry more clearly, an overall picture is be presented from a historical perspective by dividing it into two stages, based on the perspective of firms entry and exit, experiment and innovation, legitimation, market growth, competition, fulfill of industry chain, commercialization, and so on (Weil and Utterback 2005). The two stages are the formative stage and the rapid growth stage. In the former phase, the industry developed slowly, while in the latter it became a powerful player in the world market from a small initial base. After presenting the general situation of the formative phase of the Chinese PV industry, this chapter will elaborate the technological innovation systems during this period.

4.1 4.1 The Formative stage (1950s to 2002)

The world PV developmens started from 1954 that researchers at Bell Lab accidentally discovered a voltage was generated by p-n junction when lights were on (Luque and Hegedus 2011). The research of solar cells in China started quite early from 1958, nine years after the foundation of the People's Republic of China, four years after the discovery of Bell Lab (Li 2007). The actual application of solar PV did not start until in the 1970s that it has been used in space areas (Zhang 2007). At that time only small amount of solar cells have been produced by a couple of state-owned companies. Their cost was very high, while efficiency was quite low. Only applications in space could justify the high cost; due to the abundant solar resources in space, solar PV is an ideal energy source even wtih their low efficiency. Under these circumstances the first PV manufacturing firms were established in the late 1970s to help supply the demands of the pilot space and terrestrial applications launched during that period (Susan Myers, L Y Yuan 2007). The first companies were located in Beijing, Ningbo(in eastern China), Kaifeng(in central China) and Yunnan(in southern China), and they started producing solar cells by using waste raw material from the integrated circuit (IC) industry. The equipments used to produce solar cells in this period were mainly imported from the United States (Nicoletta 2007). See figure 4 for the location of these firms at the formative phase. Ningbo and Kaifeng were the two first large-scale cell manufacturers in China. They introduced key equipments into their cell manufacturing process with government support. Qinhuangdao Huamei then began its production by purchasing new solar cell manufacturing equipment and Yunnan Semiconductor starting manufacturing with second-hand production equipment. Finally, Shenzhen Yukang and Haerbin Keluona set up a non-crystalline silicon solar cell manufacturing production line (Campillo, Foster 2008). By 1990 Chinese companies in solar cell technology had established a total manufacturing production capacity of 4.5MW (Susan Myers, LY Yuan 2007).

Figure 4 Location of solar cells manufactories before 2000



In the 1990s the Chinese PV industry continued to develop at a steady rate. Central and local governments noticed the importance of PV industry and started paying more attention to its development and its market. Thanks to Reform and Opening Policy started in 1978, international trade and technology transfer became much easier. Companies started to upgrade their equipments and expand their production lines.The cost decreased from 80 RMB/w to 40 RMB/w; more areas have deployed PV systems as in communication, transportation, rural areas, and so on (Y.W. Zhao 2003, Y. M. Zhang 2007). The industry evolved by increasing its capacity and dynamic application, which could be regarded as the initial formative stage of the Chinese PV industry. Table 2 indicates the capacity of each firm in the Chinese PV industry at the time.

Table 2. Capacity of firms in Chinese PV industry in 2002

Manufactures	Capacity (MW)			
	Monocrystalline silicon	Polycrystalline silicon	Module encapsulation	a-si
	Cells/Module	Cells/ Module		
ENF	4			
Yunnan Semiconductor Device Factory	2	1		
Qinhuangdao Huamei	1			
Wuxi Suntech		10		
Shanghai GoFly Group	1			
Shenzhen Nenglian			2	
Shanghai 811			2	
Wuhan Rixin			1	
Shenzhen Xianxing			1	
Other			1.5	

Harbin Keluola				1
Shenzhen Riyuehuan				1
Shenzhen Ritar				0.5
Shenzhen Chuangyi				1
Subtotal	8	11	7.5	3.5
Total	30			

Source: Y.W. Zhao 2003, Y. M. Zhang 2007

4.2 Market Development

At this stage, application dimensions evolved from single to dynamic; although the speed was still slow due to the lack of innovation to cut down cost and incentives to encourage deployment. After being utilized in space areas like satellites, PV technology enterred into terrestrial application. Terrestrial application has started from small power systems of several watts to a few tens of watts such as “...beacon lights, railway signal systems, weather station on mountains, electric fences for stock enclosure, insect trapping lights and DC solar lights” (Li 2007:15).

During the period of the 6th and 7th Five-year Plans (1981-1985, 1986-1990 respectively), the Chinese government started supporting PV applications in other fields. The PV industry was promoted in specialized industries and rural areas, for example in solar powered microwave relay stations, military communication systems, cathode protection systems for sluice gates and oil pipelines, carrier wave telephone systems in rural areas, small-scale solar household systems and central power supply systems in villages (Li 2007). In 2002, the National Development and Planning Commission (NDRP) implemented the Township Electrification Programme (Song Dian Dao Xiang), which aimed at solving power supply problems by using PV and small-scale wind electricity generation in more than 700 townships in seven western provinces (Tibet, Xinjiang, Qinghai, Gansu, Inner Mongolia, Shanxi and Sichuan) where could not be covered by state grid. The total PV consumption was 15.5 MWp. This program stimulated the PV industry, and several production assembly lines were established since then (Table 3), which rapidly increasing the annual production of solar cells (Ruirui Zhao et al. 2011, Wu 2009).

Table 3 PV Installed Capacity in China Since 1976

Year	1976	1980	1985	1990	1995	2000	2002
Annual installed Capacity/kWp	0.5	8	70	500	1,550	3,300	20,300
Cumulative installed Capacity/kWp	0.5	16.5	200	1,780	6,630	19,000	45,000

Source: Ruirui Zhao et al. 2011, Wu 2009

4.3 Features of the Chinese PV Industry in the Formative Period

The formative phase lasted for about fifty years. During the long period, Chinese PV sector developed at a slow rate with some unique characteristics, which were influential to the technological innovation system in the formative phase.

First, all manufacturers in this period were totally state-owned enterprise (SOE)[1]. These firms highly relied on central and local governments' decision and support. SOEs at that time lacked management autonomy and were not responsible for their own profits and losses (Chen et al. 2005), because the government was. The government made decisions for SOEs deciding upon the direction of their development, and took responsibility for losses and shared profits with firms. Considering these characteristics and the closed market, factories had neither a mandate nor the incentive to experiment with the technology and innovate (Liu 2003).

Although by 1995 China had six solar cell manufacturers with a total annual production capacity of about 5MW, actual production was much lower due to serious equipment bottlenecks in different parts of these production lines (Dai, Shi 1999). During the first phase of China's PV industry, increases in production capacity were modest and new entrants did not appear in the market until the beginning of the 2000s. Suntech, a foreign-invested enterprise was established in 2001. Only three of these first generation companies (those in Ningbo, Kunming and Harbin) are still producing solar cells and modules, though under different ownership (Marigo 2007). And from the map (Figure 4) it was obvious that most companies were located in the eastern and southrn parts of China, comprising the later geographic distribution of the Chinese PV industry.

Second, in the formation stage equipment was made by developed countries and technologies applied were backward. Before 2000, China did not have any capability for making solar cell production equipment, or the innovative ability either. Some firms had to import the entire production line and key equipments

[1] Suntech, a foreign-capital invested company, is the exception. It is why I define the end of the first stage here, because the emergence of foreign invested firms indicates the market has developed to attract capital from externalsources, and the economic environment is much more open than before, indicating changes ininstitutional aspects.

mainly from the United States. Equipments imported from developed countries 15 years ago were still in use (Table 3). It is not surprising that technologies and the equipment used for photovoltaic production had been so far out of date. In 2000, in cooperation with the Institute of Solar Energy of Shanghai Jiaotong University, Shanghai GoFly Green Energy Co. Ltd. installed a production line of crystalline silicon solar cells. The firm also designed some main equipments, such as solar cell selector, module simulator, laminator, RTP furnace, and so forth. (Hong et al 2001). The laminator was adapted to efficient mass production, and had a low maintenance cost; and the module simulator used a PC with Windows 98, which had a high accuracy and fast data acquisition speed. Light intensity uniformity complied with both American Society for Testing and Materials and Japanese Industrial Standards at the same time. (H. Yang et al. 2003)

Table 4: Equipment origin of main solar cell manufacturers in China

Manufacturer	Equipment Origin	Technology
GoFly Green Energy Co. Ltd	Themselves	c-Si and multi-Si(125× 125mm^2)
Qinhuangdao Huamei Co. Ltd.	Whole line imported (Spire, USA)	c-Si (Diameter 100mm)
Yunnan Semiconductor Devices Factory	Whole line imported (TPK, Canada)	c-Si (Diameter 100mm)
Ningpo Solar Cell Factory	Key equipment imported (Spire, USA)	c-Si (Diameter 100mm)
General Institute for Non-Ferrous Metals	Key equipment imported (Spire, USA)	Multi-si

Harbin-Chronar	Whole line imported (Chronar, USA)	a-Si
Tuori	Whole line imported (Chronar, USA)	a-Si

Source: Yang et al. 2003

4.4 TIS in the Formative Stage

In the formative stage, the market expanded from single field to multiple areas in accordance with the development of PV products. This expansion was totally dependent on demonstration projects supported by the government. The government had a critical impact on the industry development as well as market cultivation. The data suggested that there was no huge gap between industry capacity and market demand. From a technology and innovation perspective, equipments were imported and innovation did not start until the last years of the formative stage. The adaption and design of equipments can be considered as the beginning of technology innovation of Chinese PV industry.

Though it is difficult to analyze the innovation system since few innovations could be traced in the formative stage, interaction between different actors still existed. The industry developed and formed into an initial base, so did the TIS.

One of the most important aspects in the formative phase comprises the radical changes in institutional perspective, which not only influenced the development of the industry, but also had a large impact on the formation of TIS. The economic and political systems adopted by the central government changed dramtically after 1978 which is a significant year in the history of the People's Republic of China. Before then, the central government implemented planned economy and communication with other countries was rare and difficult, and

China was seen as closed and secretive. Domestic conditions therefore made it nearly impossible for technology transfer to take place from developed country to China. Moreover, the economy had little vitality, since in such a centrally planned economy, the government controls nearly everything. Prices are centrally determined, and thus could not reflect the macroeconomic disturbances in market-determined price, distorting a number of behavior patterns (Feltenstein, Farhadian 1987). Thus before1978 under the control of a central government, solar PV firms had little freedom to develop and expand; and due to planned economy problems in the industry may not be reflected and further addressed, which was definitely not good for healthy industry development. The role of the government was so powerful that everything was under its control without incentives for change.

After 1978, the country began transiting to a market economy, starting with implementing the policy of reform and opening-up. With the government no longer controlling everything, the entire society became more energetic. More autonomy was given to firms that indicated they could make their own decisions. As a result, when firms competed in the market, they rather than the government took responsibility for their own decisions. Though SOEs could receive support from the government, they mostly assumed responsibility for their own losses and profits. In such cases, firms had to make changes to survive the market competition, stimulating the industry's development. The transitional institutional environment forced firms to evolve and innovate on the one hand, and provided an energetic environment for evolvement on the other.

Until the end of the 20th century, the market economy became mature after twenty years' development. The fast growth of the Chinese PV industry in 21st century benefited from changes in the economic system, and radical institutional changes facilitated its formation as well as that of TIS. It is a prerequisite at the formative stage providing an appropriate macroeconomic environment for industry development and technology innovation. It had an influence on the function resource mobilization by attracting both domestic and abroad investments to this field. The successful transition to a market economy is still essential for development of the latter.

The project *Song Dian Dao Xiang* was initiated in 2002. As the first trial to solve electricity problems in remote areas on a large scale by deploying renewable energy (mainly deploying two types of renewable energy, PV and wind energy), it fulfilled the technological transition from experiment, demonstration and final implementation. It pushed the Chinese PV industry into a positive direction that resulted in a 10-fold increase in manufacturing and shipment capacity of solar celss in three years (Chinese Renewable Energy Industries Association 2004). This served the function of knowledge development and diffusion by applying PV technology in practice in remote areas. The PV technology was diffused and adapted in this project, with many practical lessons learned, which was important for its development in latter stage.

The market was also formed and cultivated through the implementation of the project. Before the project, applications focused mainly on small scale deployments in special industries such as aerospace area and communication field, as determined by the low installed capacity combined with the slowly increasing speed. Enactment of this project drastically raised the number of PV systems and opened the market for off-grid PV systems. In addition, the project also reflected the government's determination to promote renewable energy, which definitely made the industry more attractive for investors. The resources mobilization function was also served by this project.

Another important point was adaption and new design of equipments indicating the innovation capability of the Chinese PV industry at the formative phase. At the same time it also suggests that the function knowledge development and diffusion has been served. At the end of the formative stage, firms tried to make some changes in equipments to improve efficiency in collaboration with research institutes. Though these activities were based on imported equipments and imitation of transferred technology from developed countries, innovation did happen in the adaption and design process. Innovative knowledge was generated as the emergence of improved equipments, showing that Chinese firms started their innovation experiments.

Though no fully-developed technological innovation systems was formed, there were still functions served at the formation stage (table 5).

Table 5. Functions Served in Formation Stage

Functions	**The Formative Stage**
Resources Mobilization	*Radical institutional changes* *Song Dian Dao Xiang*
Knowledge Developmeng and Diffusion	Song Dian Dao Xiang Project
Market Formation	Song Dian Dao Xiang Project Radical institutional changes

State-owned enterprises monopolized the market and no private firms could compete with them. The market system could not fully function in the formative stage to promote industry development and technology innovation. Innovation mainly based on imitation and adaption to technology transferred from developed countries. As a technological innovation system, it was still at infant phase with few functions being fulfilled. However, by importing and imitating advanced technology from developed countries, it started the formation of technological innovation system of the Chinese PV sector for development in latter stages.

5. The Rapid Development Stage and TIS

After pre-development in economic environment, the Chinese PV industry entered a stage with impressive growing speed. The rapid growth of the Chinese PV industry since 2002 manifested itself as follows:

From 2002 to 2009 Chinese PV industry shipments increased from 10 MW to 4000 MW (Table 6). The average annual growth rate (111.74%) is much higher than the world annual average growth rate (44.56%).

Table 6 Annual shipment and growth rate of solar cells in the world (MW)

Year	2002	2003	2004	2005	2006	2007	2008	2009
China	10	10	50	200	400	1088.0	2600.0	4000.0
Europe	135	193.35	314	470	657	1062.8	2000.0	2800.0
Japan	251	363.91	602	833	928	920.0	1300.0	1800.0
The USA	120	103.2	140	154	202	266.1	432.0	600.0
Others	45	73.8	89	102	314	213	668.0	500.0
Total	561	744.26	1195	1759	2501	4000	7900	10700
Annual Growth Rate (%)	44.0	32.7	60.56	47.2	42.18	59.94	97.5	35.4

Source: Data from Li et al. 2010

The increase in the number of players in this field was the direct reason for the industry's fast growing capacity. Another reason is firm expansion. For example, Suntech expanded its solar cell and module production capacity from 10 MW in

2002 to 1GW in 2009. Table 7 show that six Chinese companies are among the top 15 solar cell manufacturers, and the number would rise to eight if Taiwan were included. China has become one of the largest production areas in the world in less than 10 years.

Table 7. Shipments of the Top 15 Solar Cell Manufacturers in the World in 2008 and 2009

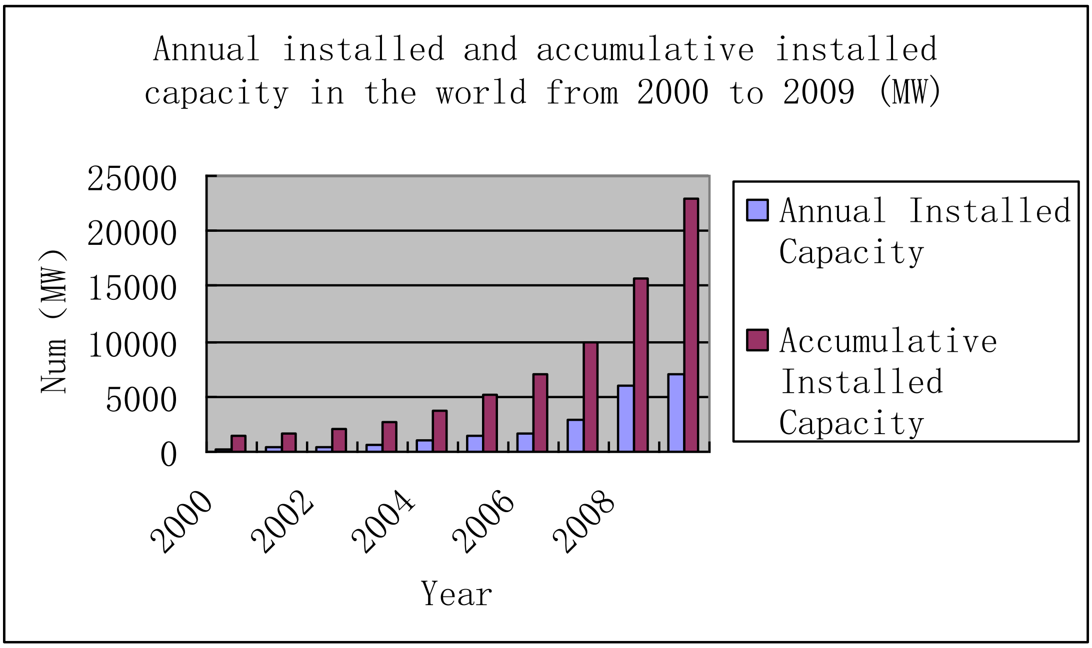
NO.	Manufactory	2008		2009		Growth Rate (%)
		Shipment	Proportion (%)	Shipment	Proportion (%)	
1	First Solar (US,DE,ML)	504	6.4	1092	10.2	116.7
2	Sharp(JP)	473	6.0	870	8.1	83.9
3	Q-cell(DE)	570.4	7.2	800	7.5	40.3
4	Suntech Power(CH)	497.5	6.3	705	6.59	41.7
5	Baoding Yingli(CH)	281.5	3.6	527	4.93	87.2
6	JA Solar(CH)	277	3.5	504	4.71	81.9
7	Trina Solar(CH)	209	2.6	426	3.98	103.8
8	Kyocera(JP)	290	3.7	400	3.7	37.9
9	Motech(TW)	272	3.4	400	3.7	47.1

10	Sun Power(PH)	236.9	3.0	350	3.3	47.7
11	Canadian Solar(CH)	105.4	1.3	316	2.95	199.8
12	Solarfun(CH)	189	2.4	315	2.94	66.7
13	Sanyo(JP)	210	2.7%	300	2.8%	42.9
14	GinTech(TW)	180	2.3	300	2.8	66.7
15	Solar World(US,DE)	221	2.8	250	2.3	13.1
Total		4516.7	57.17	7555	70.6	67.3

Source: Jäger 2011

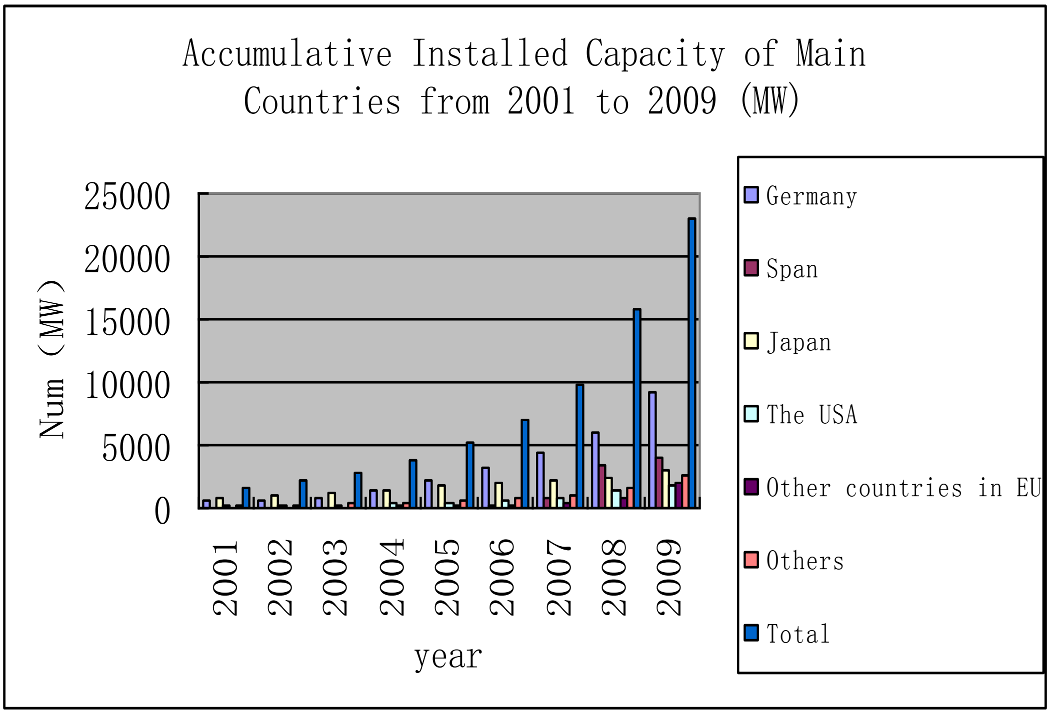
One of the aims of the economic reform in 1978 was to restructure domestic industry to be profit-oriented rather than controlled by a central government (Jefferson and Rawski 1994). According to Smith's (1976) hypothesis of the economic man, individuals pursue maximum profits. When similar firms develop and comprise of an industry, profit is the main factor influencing the industry's direction. The impressive expansion speed of the Chinese PV industry was due to the speedy growth of the world PV market. Developed countries especially reealized the important role of renewable energies in relation to national energy, security, and environmental issues, and many policies have been adopted to promote their development. Solar PV has attracted attention as a renewable source of energy, leading to supportive policies in such countries as Germany, the United States and Japan. The market was cultivated in these countries and demand has greatly increased (Table8), which stimulated the Chinese PV industry to expand to share in the profits. Global accumulative installed capacity grew from 1692 MW to 22,901 MW in less than 10years, with these countries accounting for more than 79% of the growth(Table 9).

Table 8. Annual installed and accumulative installed capacity in the world from 2000 to 2009 (MW)



Source: Yan et al. 2009

Table 9. Accumulative Installed Capacity of Main Countries from 2001 to 2009 (MW)



Source: Despotou 2010

5.1 Current status of Chinese PV Industry Supply Chain

The performance of Chinese solar cell and module manufacturers in the world market is impressive, and it would be interesting to examine the industry chain to see how it functions.

Most PV cells and modules produced by Chinese manufacturers are silicon-based, and thin-film cells are still in the experimental stage, with little production (see Figure 4). This thesis focuses on monocrystalline and multicrystalline cells and modules.

5.1.1 Silicon

Polysilicon is the main raw material for the manufacture of silicon-based solar cells. Formerly it is used mainly in the semiconductor industry. Polysilicon is now consumed in greater amounts by the PV industry. Over the past two years, shortages and price spikes have been the result of the rapid development of the world PV market (McKinney 2008). Since the speed of development is so great, there is a big gap between demand and supply, which increases the cost of he raw material. With the rise in raw material prices and rumors of idle cell production capacity, the lack of silicon has become a bottleneck in the growth of the PV industry (Flynn and Bradford 2006). The Chinese PV industry faces similar problems, perhaps even worse ones. In 2005 the global capacity for polysilicon production was 31, 280 MT, with Chinese manufacturers producing only 130 MT that year, only 0.4% of the total amount Flynn and Bradford 2006). This small amount can be ignored, especially when compared with the amount of solar cells Chinese manufacturers produced the same year. Chinese manufacturers had to import raw materials from developed countries such as Germany, and the United States which greatly raised cost, and thus reduced profits. In addition the Chinese PV industry became more vulnerable to any fluctuations in silicon prices or supplies in the world market.

The industry and the government have both realized the problem of insufficient silicon supply from domestic firms. Many projects were planned and implemented to change the situation (See Table 9 for development of the Chinese PV industry in 2008 and 2009). Capacity and output amounts both greatly increased. In 2006 about 97% polysilicon was imported. The number was expected to decrease every year through the operation of newly-built production lines.

Table 9. Overall Picture of Chinese PV Industry, fiscal years 2008 and 2009

Industry Chain	2008		2009		Number of Manufacturers
	Capacity	Output	Capacity	Output	

Polysilicon(t)	20000	5000	60000	16000	48
Wafer(t)	30000	25800	50000	40000	80
Cells(MW)	4000	2600	9000	4000	100
Modules(MW)	5000	3000	10000	4100	330(18 firms produce thin-film modules)
Industry Output Value(Billion RMB)	2000		3000		
Employee	200 000		300 000		

Source: Li et al. 2010

5.1.2 Wafer Production

By mid 2005, there were fewer than 10 mono- (mono-Si) and polycrystalline (poly-Si) wafer manufacturers in China, with a total capacity of 71.5 MWp (Marigo 2007). They were unable to satisfy the domestic cell demand not only because their capacity was limited, but also because, as noted, less than 20% (between 15 MW and 20 MW) of their wafers were for the internal market (Wang 2006). At that time wafers were imported just like silicon. Table 8 shows that more wafer manufacturers entered the industry through 2009, and capacity has greatly increased and the industry chain has been somewhat rebalanced. However, it is clear that cells and modules manufacturers are still the main players in the Chinese PV industry chain.

5.1.3 PV Cells

Solar PV cell production expands every year. Since 2004, the annual rate of increase of the Chinese PV cell industry has remained at more than 100% in five years, and since 2007 until now China has ranked first in the world output of PV cells. The numbers are astonishing and indicate the fast development and expansion of PV cells production in China.

5.1.4 Modules

The multitude of module producers with limited production capacity is not surprising. Assembling cells into modules does not require the same level of technical expertise needed in wafer and cell production, and putting into peration a module assembly line is technically easier and faster than setting up a cell production line. This is particularly true if the module assembly line is partially or even fully manual, which is often the case with the Chinese module producers (Marigo 2007). One of the informants mentioned that when he visited one Chinese module factory, he found few machines but many people working around tables, while a Germany factory he visited was fully automated. This indicates that some firms, especially small or medium-sized firms, profits from the cheap costs of labor, energy, land use and so on in China rather than any advanced technology (Matsui: interview 26.04.11). This suggests the particular nature of the Chinese PV industry. It remains to be seen whether such firms can survive future competition. Figure 5 shows more specific information about the distribution of firms in the industry chain, and Figure 6 shows their geographic locations.

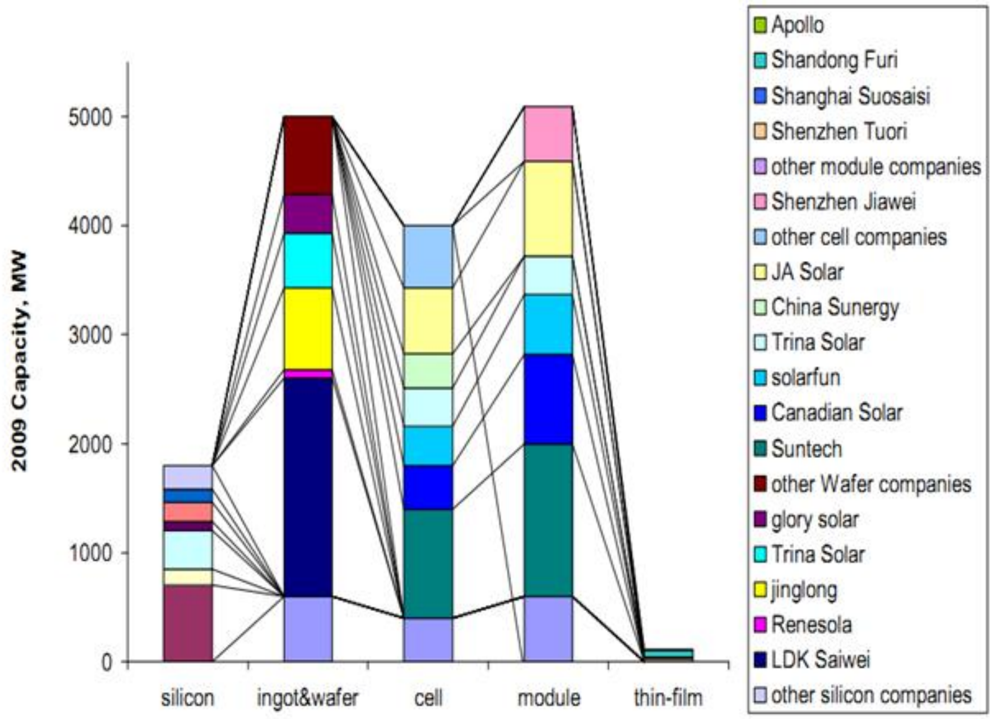


Figure 5. Distribution of Firms along the Industry Chain

Source: Company website; China PV Industry Development Report 2008; Grau et al. 2010

Figure 6. Geographic Distribution of Main PV Manufacturers

In the rapid growth stage, the ownership of manufacturers is more dynamic, involving joint ventures, private as well as foreign ownership. It is quite clear that all producers are motivated by global market demand and do not depend upon the central government's priorities or decisions. At the rapid growth phase the domestic market plays a marginal role in the sales of domestic producers (Marigo 2007).

The market share in upstream segments is much lower. China produced just 2.5% of the world's silicon in 2007 (Winegarner, 2009) while the US, Germany, and Japan account for more than 80%. Chinese firms are however planning important capacity increases that will allow them to produce more silicon in the near future. These projects are strongly supported by the Chinese government. The pattern is similar for ingots and wafers: China still represents a minor portion of world production, but it is tryting to develop quickly to increase its manufactory capacity.

Another interesting point is that Chinese PV companies have benefited strongly from the arrival of highly skilled executives bringing capital, professional networks, and technology acquired in foreign companies or universities to China (De la Tour et al. 2011). This can be demonstrated by examining the background of board members on their firms' websites. For instance, the founder and chief executive officer (CEO) of Suntech, China's largest PV Company, studied at the University of New South Whales in Australia; and then worked for the Australian company Pacific Solar. In addition, four out of the six members of the Suntech board studied or worked in the United States or the United Kingdom. The CEO of China's second largest PV company, Yingli, also studied abroad. At Trina Solar, half of the 12 person management team have studied or worked abroad. On average, 61% of the board members of the three largest Chinese PV firms have studied or worked abroad. Chinese students who studied abroad have become a main channel for technology transfer at the fast development stage. This also implies a deficiency of higher education in this field for later discussion.

5.2 Mapping the TIS of the Chinese PV industry

After the brief presentation of the industry status in the rapid growth stage, TIS in rapid growth stage will be elaborated in the left chapter. In the rapid growth stage, the system is more fulfilled to support the development of the industry.

5.2.1 Identifying Structural Components in the TIS System

In accordance with the industry's development, the innovation system of PV technology has developed into a fairly complete system, compared to that in the formative stage, which is the focus of the analysis. This starts by mapping the TIS by identifying the structural components of the system.

Actors[1]

Systems are networks of a set of interlinked activities and actors (Fagerberg 2005). Identifying the interlinked actors is the first step in studying such a system. The first and easiest actors identified are firms involved in the whole industry chain, including up-stream and down-stream firms. In the Chinese PV industry, the amount of firms keeps increasing. New firms involved in upstream and downstream activities keep entering the industry, although most choose downstream activities. The existing firms are ambitious, with large expansion plans.

The second type of actor comprises industry associations. The China Photovoltaic Industry Alliance is an example of a national industry association. There are also similar organizations at the regional level. Due to the impressive performance of the PV industry in past years, more and more local governments are trying to attract investments to set up PV firms, which can create job opportunities for locals, as well as contribute to the local economy. The emergence of PV firms in many provinces then promotes the appearance of industry associations at the provincial level. Organizations like industry associations could work as a bridge between firms and government by convey messages between them (Lei interview: 08.03.11).

The third type of actors comprises universities and research institutes, which definitely play a critical role in generating technology innovation. The establishment of two key-state laboratories is significant to system function and industry development. In 2007 MOST decided 37 research branches for following couple of years; renewable energy was excluded at that time. In 2009 MOST issued a document in which biomass, solar PV, and wind energy were

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[1] Berget et al. indicated a number of available methods to identify actors involved in a certain TIS, such as industry associations, patent analysis, bibliometric analysis, and interviews and discussions with experts. This thesis identifies the actors through an integration of these methods.

made a focus of energy field of key state laboratories[1]. After a comprehensive evaluation, Yingli Solar and Trina Solar won the bid. These firms are establishing laboratories with more than 100 million RMB of support from the central government. Trina Solar has promised to invest 5% of its annual sales revenue each year into the research lab. The two labs have different research interests: lab based Yingli Solar focuses on the manufactory and characteristics of silicon materials and, solar cells and modules high performance and deployment systems. The other lab is concentrated on solar cells and solar cell materials with a high performance-price ratio, modules of high efficiency and reliability, smart systems, and building integrated PV system. The lab experts include top domestic and international. Recently Trina Solar released news of having signed an Industry Alliance Agreement with the Massachusetts Institute of Technology, which will greatly increase the chances of close cooperation between Trina Lab and top U.S. universities. At the end of September 2011, the first meeting of the lab committee took place in Baoding, and it decided to employ 14 experts as members of the Academic Committee for Technology Innovation. The lab, with about 540 million RMB in total investment, will be brought into operation by the end of 2011.[2]

The establishment of two key state laboratories is a signal that the PV industry is on the national agenda. Although it is already behind that of some advanced nations， such as the United States, at least the Chinese PV industry is finally underway. Usually a nation sets up key laboratories at its top universities or research institutes, since its best scientists usually work there. This case is a little bit different. Companies were chosen to set up labs. This unusual method indicates that usually labs aim to generate new technology. The two key labs here

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[1] Information is retrieved from the websit of the Ministry of Science and Technology of the People’s Republic of China (MOST). http://www.most.gov.cn/kjbgz/201007/t20100712_78385.htm

[2] Information is retrieved from Trina’ official website

aim to not only generate new technology, but also to solve problems companies encouter during manufacture and operation. This approach can render the research more practical and market-oriented, suggesting that the government is willing to finance the research of PV technologies and support the commercialization of PV products.

From the focus of the two labs, one can tell that Yingli's lab is mainly about materials upstream of the industry chain, while the Trina lab basically involves efficiency and deployment downstream of the industry chain. Both labs are likely to cut costs, cultivate a domestic market, and enhance the competitiveness of Chinese PV companies in international business. The full industry chain is covered to strengthen downstream capacity and improve the ability to produce materials.

The fourth type of actor here refers to the National Solar PV Product Quality Supervision and Inspection Center (CPVT), whose main responsibility is the testing and certification of solar PV products, standards formulation and research, the dissemination of technologies, and the publication of relevant information. As a third-party fairness organization, its test results have a legal effect. However, firms prefer to use tests from developed countries to enter the international market, since most products are exported.

The fifth type of actor comprises various non-commercial organizations involved in the system. These organizations can be international—such as the WWF, the United Nations Development Programme, and the World Bank—or national, like the China Photovoltaic Society (CPVS). They facilitate international cooperation as well as offer project funding. A representative case is the Renewable Energy Development Project (2001-2006) funded by the WB and the Global Environment Facility (GEF) to provide power through wind/PV hybrid systems to remote areas, such as Qinghai, Gansu, Inner Mongolia, Xinjiang, Tibet, and western Sichuan (Chang and Bruyninckx 2009).

The sixth type of actor is the government, including different departments of the government and governments at different levels. The government plays the extremely important role of policy-making in industry development, technological innovation, or/and subsidies for application. The success of the industry in Japan, the United States, and Germany could not have been achieved without governmental promotion and support (Erge et al. 2001, Shum and Watanabe 2006).

In August 2011, the Chinese central government issued a feed in tariff (FIT) for PV application. Besides the influence of this policy, it is interesting to note that before this regulation was issued, governments at the provincial level had set up their own FIT for solar PV project. In 2009, for example, the government of Jiangsu, a province located on the east coast of China, published its a*nnouncement of Suggestions on Promoting Solar PV Applications in Jiangsu Province,* which sets FITs for territorial PV projects, rooftop PV projects, and building integrated PV systems after analyzing the development and status of the solar PV industry and annual sunshine conditions in Jiangsu province. The prices for territorial PV projects, rooftop PV projects, and building integrated PV systems decreased with time: 2.15 RMB, 3.7 RMB, and 4.3 RMB per kilowatt-hour, respectively, in 2009; 1.7 RMB, 3 RMB, and 3.5 RMB per kilowatt-hour, respectively, in 2010; and 1.4 RMB, 2.4 RMB, and 2.9 RMB per kilowatt-hour, respectively, in 2011.[1]

Shandong Province, another province along the east coast, announced a similar policy in 2010.[2] Qinghai province, in western China, set its FIT right before the NDRP and also claimed that if the FIT from the central government is lower, they would pay for the gap. As a less developed province with abundant sunshine, this

[1] For specific content, please refer to the full translation of the announcement in the Appendix.

[2] The same as the above.

may be a good opportunity for them to promote PV applications to improve the local economy. All have shown stronger determination and support from local governments which also puts pressure on the central government to apply FIT policies at the national level.

Networks

Generally, there are at least two kinds of networks: links between universities/research institutes and firms and networks between firms. In the former network, many firms, especially large ones, have close cooperation relationships with universities/-research institutes, even universities abroad. Suntech, for example, has been in long-term cooperation with the University of New South Wales (UNSW) because Suntech's CEO earned his PhD degree there. As the technology in developed countries advances, relationships with the world's top universities allow firms to be engaged in top technology activities, which, in turn, may generate technology innovation.

There are no direct materials to indicate close links between Chinese PV firms. However, there exist data about the links between Chinese PV firms and firms abroad. The Jinglong Group is the world's largest monosilicon producer, with a production capacity of 3000 tons and an output that was 50% of China's total production in 2006. Jinglong has joined in the expansion plan of the world's largest polysilicon producer, Hemlock Semiconductor Corporation (HSC), and signed a long-term supply contract. Some large cell and module producers such as Suntech, JA Solar, and Trina Solar also keep close cooperation relationships with silicon suppliers in the United States, Germany, and so on, to secure their silicon supply (Campillo and Foster 2008). This relationship ensures a silicon supply to Chinese manufacturers, which is the main weakness of the Chinese PV industry.

Institutions

Institutions can be both tangible and intangible, as in norms, laws, regulations, and standards. These elements influence the interactions between actors and etworks within the TIS in different ways (Berget et al. 2008, North 1994). Among regulations related to the PV industry, the following are important.

Renewable Energy Law

The Renewable Energy Law was issued in 2005 and has been in force since January 1, 2006. This fairly general law encourages the development and expansion of renewable energy sources. It formulates some basic rules for the development of renewable energy, determines the obligations of certain related departments—such as governments at the regional level and the grid company—and protects the rights and interests of renewable energy companies through preferential tax policies, for example. Undoubtedly PV cells are included as a kind of renewable energy source.

According to Renewable Energy Law, there are three rules about the price of electricity generated by renewable energy.

a. The grid company must purchase all the electricity of the renewable energy.

b. The FIT should cover reasonable costs plus reasonable profits.

c. An excess costs higher than the tariff of conventional power will be shared by the whole country.

The Renewable Energy Law has put forward a comprehensive renewable energy policy framework and institutionalized a number of policies and instruments for the development and utilization of China’s renewable energy (Zhang et al. 2010).

Management Rules for the Renewable Energy Additional Tariff

In 2007 the National Development and Reform Commission (NDRC) issued its Management Rules for the Renewable Energy Additional Tariff.

a. Since November 2009, 0.004 RMB per kilowatt-hour is charged as a renewable energy tariff, and the annual income from all of China will be 12 billion RMB to -20 billion RMB.

b. The FITs for wind and biomass power have been clearly set (0.51-0.61 RMB per kilowatt-hour for wind power, and a coal-fire tariff of +0.25 RMB per kilowatt-hour for biomass power), but not yet for the PV industry.

c. Green Certificates are traded -between provinces every six months.

Temporary Subsidy Methods of Building Integrated PV Projects

In 2009 the Chinese Ministry of Finance issued the Temporary Subsidy Methods of PV Building Projects.

According to this publication, projects with over 50 kWh and higher efficiency (->16% for monocrystalline silicon products, >14% for polycrystalline silicon products, and 6% for amorphous silicon products) can apply for financial support. Applications should be submitted to the local financial and construction departments and then to the same departments at the provincial and national levels. The department at the national level will examine and verify the amount of financial support. A total of 70% of the finances would come to provincial financial departments and then projects after cooperation with construction departments. After the projects are finished and pass evaluation, they may be eligible to receive the remaining 30% of funds.

New released FIT

On August 1, 2011, the NDRP released a refined PV FIT, which had been expected by industry players and people interested in renewable energy. FITs have contributed greatly to the European PV market, as in Germany and Spain, both of which contributed greatly to the increase in PV applications. Although central and local governments have issued supportive policies and regulations on the PV industry or its applications, the lack of FITs is always considered the main problem of an undeveloped domestic market. This sentiment was also emphasized by most of the interviewees, who argue that without a systematic and long-term supportive policy system, it would be very slow and difficult to develop the Chinese PV market due to high costs.

This is not good for the Chinese PV industry, since the international market is developing slower than the Chinese PV industry is expanding, and the number of FITs is decreasing. The lack of domestic incentives for PV technology innovation leads to under-developed supporting mechanisms, such as undeveloped research on PV technology in research institutes and universities, and persons training in this field in China.

This new policy mainly defines the FIT in China[1] as follows:

- For solar PV projects approved for construction before July 1, 2011, and finished and operated before December 1, 2011 without a ratified price, the unified price is 1.15 RMB per kilowatt-hour (tax included, the same below)
- For solar PV projects approved for construction after July 1, 2011, and projects approved before July 1, 2011, but unfinished until December 31, 2011, the unified price is 1 RMB per kilowatt-hour (for Tibet, the price is still 1.15 RMB per kilowatt-hour). The price would be adapted according to variations in investment cost, technology innovation, and other factors by the NDRP in the future.

The fact that China has set its own FITs indicates the determination and support of the national government for PV technology and industry. Most analysts believe that this policy will be positive for the development of the domestic market and the industry. But there is a question as to how much positive impact the policy has, since it is not specific enough, such that it has not mentioned the duration of

[1] Originally in Chinese and translated by the author.

this benchmarking policy. This uncertainty leads to the FITs contributing less to the system function. FITs can mitigate some risk in investing renewable energy to cultivate the market; however, to a large extent uncertainty still exists, since the effective period of FITs is unclear. Investors cannot be sure that they will lose money if it is just a short-term policy. Moreover, since China is a large country, sunshine conditions vary by location, which means different return periods on investment. To promote its development in different areas in China, it definitely should be improved.

For manufacturers, the situation varies. Large manufacturers would be capable of benefiting under the price and boosting their domestic market share, while medium-sized and small companies would face a very tough time (Shawn 2011). Large manufacturers are able to reduce costs by expanding their production lines and technology innovations. Lower costs are important in competition. Medium-sized or small companies have little ability to reduce costs to face market fluctuations. Since the FITs are not very high, it is possible for large firms to make profits, but it difficult for medium-sized and small firms. In the international market, FITs in developed countries such as Germany are decreasing. Medium-sized and small companies are facing a difficult situation; some have even stopped manufacturing activities due to overproduction, and their products have become less competitive in the market (Han 2011).

Research and development (R&D) projects are usually regarded as an important way of solving problems in practice. Though there were no FITs before August 2011, there still existed some R&D projects to promote technology development.

The first is the Brightness Program, an international effort designed to give locals access to electricity. Since the Brightness Program was introduced during the 1996 World Solar Peak Conference in Zimbabwe, China has played an active role in it. It established its Brightness Project Implementation Planning in 1998 and the project has been since progressing in stages.

China's Brightness Program applies both, wind energy and solar energy. Its overall goal is to provide electricity for 23 million people in remote areas by 2010, using renewable energy technologies, eventually providing 100W of capacity per person. China's State Council has allocated about US$50 million (USD), or 400 million RMB, to support the Brightness Program during the 10th five-year plan period (2001-2005). The program will provide electricity by using both household and village systems and will focus on Gansu, Qinghai, Inner Mongolia, Tibet, and Xinjiang provinces. The costs are expected to be covered by the users, local government grants, central government grants, and foreign grants(NREL). This is the first wide application of solar PV modules and it tests the off-grid PV system.

The Golden Sun Project is another very important R&D project. In July 2007the Ministry of Finance, the Department of Science and Technology, and the National Energy Board jointly released the national subsidy demonstration program Golden Sun Project, which provides upfront subsidies for qualified demonstrative PV projects during 2009-2011. Unlike the Brightness Program, the main target of the Golden Sun Project is to support and finance both off-grid and on-grid PV systems of no less than 300 KW each. A total of 10 billion RMB will be invested to finance this project. Under this scheme, the government said it would pay 50% of the investment for qualifying solar-power plants and transmission and distribution projects. For projects in remote regions not connected to the grid, the subsidy would rise to 70%. This round of subsidies can be seen as the Chinese state's strongest ever show of support for the solar PV industry. The project includes many projects located in different parts of China. The construction of each project is allocated through public bidding, and those who can offer the lowest prices may get the contract.

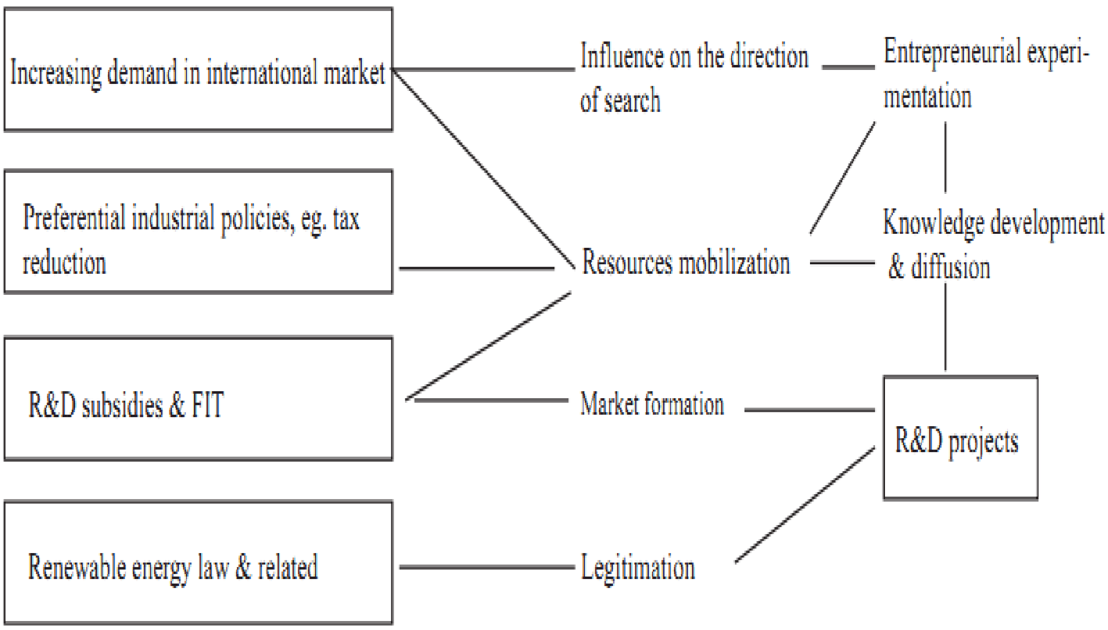
The City Road Light System is a project closely impacting the daily life of all citizens, for it is attempting to power all city lights with solar PV systems rather than conventional energy. Billions of dollars are expended to pay for the expense of electric power, which has become an enormous burden for the Chinese government, To support such lights, more than 2 million tons of coal must be burned annually, emitting a huge mass of polluting CO^2 and SO^2 (Liu et al. 2010). As a solution, solar energy is utilized in the city road lighting system by some local governments to improve the environment, that is, solar energy street lamps, solar energy community lighting, and solar energy scenery lighting, with solar energy street lamps having better competition and becoming more popular. Increasing numbers of cities throughout China have begun replacing conventional street lamps with solar energy street lamps. For instance, Baoding, a small city in Hebei province near Beijing, has been equipped 102 of its main roads in urban areas with solar traffic lights. At the same time, the road lamps of 37 sections have been replaced, and 700 solar lights have been installed. The public lighting of 159 housing estates has been equipped with solar lights. Solar energy has been applied in nine gardens and in the greenbelt, and 2654 solar lights have been installed, covering 85.3% of Baoding’s urban area (data from the Baoding government). Of course, these systems are also connected to the conventional grid to make sure they can work normally when the PV systems cannot generate sufficient power.

The most important point of this project is its ability to bring PV technology closer to citizens, making them understand that the technology is capable of generating electricity in daily life. I have talked to a couple of persons on the streets in Baoding, where many streetlights and transportation lights are supported by solar PV. They demonstrated a basic knowledge of PV technology and expressed that they welcomed solar PV street lights and would like more PV applications in their surroundings. However, the residents of other cities showed an insufficient knowledge about PV technology and some had no idea what the term solar PV means. This project can thus be considered a prelude to later projects, such as roof-top or residential PV systems.

5.2.2 Mapping TIS Pattern

After the actors and networks interlinked in the system are identified, the TIS pattern is mapped and elaborated upon (see Figure 7). The rapid growth stage is characterized by fast industry growth with slow market expansion. The rapid growth was initially stimulated by increasing market demand in Europe, especially Germany, which influenced the entrepreneurial experimentation function by trigging a number of new entrants into the industry. Participants increased quickly from under 20in 2002 to more than 3500 by 2009. Most are at the down-stream of the industry chain, which means that most entrants chose to manufacture cells and modules due to the lower technological requirements of the process.

Figure 7. TIS at the Rapid Growth Stage



At the same time, firms at up-stream of the industry chain have developed as well, triggered by the silicon bottleneck. The international market continues to outpace silicon production growth. Silicon thus becomes a bottleneck of the PV industry, raising its price, and causing silicon production to become more profitable than manufacturing cells and modules. China imported more than 90% of its wafers before 2008, while about 90% of cells and modules are exported. This phenomenon has induced more mature PV firms to expand their production line up-stream, and some silicon and wafer producers have decided to amplify their production lines by several times. This can diversify establishing firms and help balance the industry chain, rendering the industry more independent, rather than vulnerable to adjustments in the international market.

The phenomena described above have also influenced the “knowledge development and diffusion” function. In the beginning, PV knowledge was dominated by developed countries, and Chinese players had to import entire production lines. By the end of the formative period, adaption and innovation had been achieved based on the imitation of advanced technology. At the rapid growth phase, the technology was transferred from a different channel. Chinese students who studied abroad brought in technology and established firms in China. They developed close relationships with both domestic and foreign universities to generate new and advanced technology to keep the firm competitive in the market.

Suntech Power is a typical example. The firm was founded in 2001 by Dr. Zhengrong Shi, who studied solar technology at the University of New South Wales, receiving a PhD there. By establishing Suntech in Wuxi, China, technology was introduced. This is how Chinese firms acquired technology in the first step. The technology was then developed and diffused as the industry chain expanded. Suntech still keeps a close relationship with the University of New

South Wales that has contributed a great deal to its R&D departments. This approach has become the model for diffusing and generating knowledge in the Chinese PV industry.

Since the first R&D project Song Dian Dao Xiang, a number of R&D projects have been supported by governments, serving the “technology development and diffusion” function. The lessons and application experience acquired from R&D projects are critical to later commercial use.

However, R&D projects have failed to serve the function “market formation” which is one of the reasons leading to a weak domestic market. Although there have been a number of R&D projects in China in the past ten years, interviews with industry players reveal that most of them gave up the domestic market and set their sights on international markets such as Germany. One informant[1] explained that projects sought partners through an open bidding process which is usually special in China. First, the information is usually not transparent enough. This is advantageous to big, state-owned enterprises which have a good relationship with the government. Secondly, the government chooses the one who offers the lowest price. Some big firms want to seize the share of domestic market by price advantage because they are big enough to afford non-profitable projects. The bidding price for a large-scale PV power generation located in Dunhuang, Gansu province was only around 0.69 RMB per kilowatt-hour, which made it difficult for private firms to make profits. As a result they had to give up domestic market. Third, there are no long-term subsidy policies which make the market risk and unreliable. On the contrary, countries such as Germany and Spain with a systematic supportive policy are more ideal for those firms to enter. With the subsidy from governments, these markets seem quite tempting. And Chinese firms are usually known to have a price advantage for low labor and energy cost.

[1] Invert producer, an anonymous informant.

The industry-friendly environment created by governments continues to positive promote industry expansion. The market economy that evolved during the formative period matures in the rapid growth stage. Another critical aspect of the industry-friendly environment is the preferential policies of national and local governments. Due to working placements created by those firms in the PV industry, especially for cells and modules production, which is labor-intensive, and the taxes such firms contribute, local governments offer a series of preferential policies to attract them to set up factories. This has encouraged new entrants to the field and existing firms to expand their production lines. For example, JA Solar is constructing a production line in Hefei's high-tech Zone. This is very common in China, where nearly every city has set up a high-tech zone to attract investments by offering a series of favorable policies, not limited to the PV industry. Governments then have to support firms when there are problems arising in this industry, for they do not want to increase the unemployment rate and reduce tax revenue, which can press governments into creating more favorable policies and regulations to reinforce the positive environment for development. Clearly this serves the function "resource mobility" through attracting more capital to the field. The dynamics of PV firm ownership show that various kinds of capital can enter the field. Sufficient resources are prerequisites for Chinese PV industry expansion.

However, this phenomenon can weaken other functions, such as "entrepreneurial experimentation", and then further the function "knowledge development and diffusion". Some firms without mature technologies can also make profits because of the low cost of energy and labor in China. Favorable local government policies can also increase the possibility of earning money without technology innovation. This explains why one informant mentioned that he saw staff working around tables in Chinese module factories while in Germany he found the production line to be fully automated. If profits can also be made without technology innovation, then firms, especially small ones will naturally be reluctant to spend money in pursuing technology innovation that is not only costly but also highly risky. However, such firms cannot survive for long, since competition is becoming fiercer and fiercer with time.

Some new small firms have had to stop production. According to the editor I communicated with, some small and medium-sized firms have had to stop production due to the gap between supply and market demand. Since there is no technological advantage, the only advantage would be low costs. But small to medium sized firms cannot achieve low costs, either by advanced technology or scale merits through expansion, and it is now different for them to compete. This can facilitate the development of industry in the beginning, but it cannot be sustained for long.

The influence on the direct of search is due to certain incentives or/and pressures that push the actors to do conduct research in a certain direction. Silicon and wafer production are bottlenecks in the global PV industry, and the Chinese PV industry is not an exception. China has a very severe problem, since products of up-stream are more profitable and are dominated by developed countries. Strong dependency on imports can greatly reduce profits. From the increasing output of silicon and wafer, the ability of silicon and wafer production has been enhanced in the rapid growth period, stimulated by increasing concern about the silicon bottleneck.

The last function legitimation is formulated as the industry develops. When a number of new entrants rush into the industry, standards and regulations to protect their interests are necessary and important. At the same time, proper standards and regulations are needed to make sure the industry develops in a healthy manner. The Renewable Energy Law issued in 2006 revealed acceptance and determination of developing renewable energy, including PV technology.

5.3 Summary

The discussion above determines that the performance of innovation in the Chinese PV industry is not as good as its economic performance looks. After defining the structure of the TIS of the Chinese PV industry, each function is examined in turn. The findings explain that even though a TIS has formed in the PV sector, the system is not mature; in other words, not all functions are well served, leading to failure in innovation results and market formation.

Among functions served in the system, functions of influence on the direction of research and market formation can be considered as failing to be fulfilled. Among the left five functions, “the diffusion and development of technology” is not fully served, since most activities mentioned are about the diffusion of technology; less innovation are generated. The “development of external economies” is served by preferential government policies. However there should be more regulation for this function influences “resource mobility”, leading to some small- and medium-sized firms with no competitive ability. The last two functions “entrepreneurial experimentation” and “legitimacy” are served but should be enhanced.

6. Conclusions

Renewable energy, as a sustainable and clean source of energy derived from nature, has been encouraged and developed in many countries because of shortages in fossil energy, adverse impacts on the environment of conventional energy and energy sustainable issue. China is an emerging economy with increasing energy demand and decreasing environment quality. To facilitate domestic energy security and diversity as well as improve environment without damaging economic growth, the promotion of renewable energy is important and urgent for China.

In China, having implemented some incentive measures and subsidies, some progress of renewable energy has occurred such as development in wind energy area. This study applied the technological innovation system (TIS) framework to analyze the evolution of PV in China. The trajectory of Chinese PV sector development is quite interesting due to the large gap between manufactory capacity and domestic market. At the formative stage, the analytic result shows that the TIS of the formative phase in China was not fully developed but that some functions such as knowledge development and diffusion had already been served. Entrepreneurial experimentation had already taken place at the formative phase characterized by imitation through technology transfer of importing production equipments from developed countries. This led to knowledge development and diffusion at the formative phase. Market formation, legitimation, resource mobilization and positive externalities were however underdeveloped at this stage. In addition structural development such as the emergence of firms, research institutes and networks was initiated, but did not take off until the system moved into a growth phase. Another important factor at the formative stage was the dramatic institutional change from centre-planned economy to market economy, which facilitated technology transfer, resources flow and market competition establishing an industry-friendly environment for PV sector expansion in later phase.

At the rapid growth period, the industry expanded in a fast speed while the market continued to increase at a much slower pace. Comparing with the formative stage, TIS in rapid growth phase has been much better served reflected by more functions have been met (Table 8), though not all functions have been developed equally.

Table 10 Comparison of function pattern between the formative stage and rapid growth stage

Functions	Formative Stage	Rapid Growth Stage
Knowledge development	Yes	Yes
Influence on the direction of search	No	Yes
Entrepreneurial experimentation	No	Yes
Market formation	Yes	Yes
Legitimation	No	Yes
Resource mobilization	Yes	Yes
Development of positive externalities	No	Yes

While the industry developed in an astonishing speed, the domestic market was still at an infant stage and did not grow at the same rate, which to some extent reveals problems existing in the rapid growth stage. The first problem is the ambiguity in supportive policies. Before the issue of FIT, there did exist subsidy policies to promote PV utilization. However those subsidies policies are not long-term and fixed. The subsidies vary from project to project. This could indicate that it is not certain that the government would support PV development in long term. Policy measures hence did not reduce uncertainty sufficiently in order to stimulate large scale market growth. It could result in hesitation and reluctance for prospective investors to invest in this industry. Uncertainty even exists related to the recently issued FIT. For instance it has not clarified how long the policy would be valid, which undoubtedly would influence investors' decision. Also the fact that solar resources distribution varies in different areas has not been considered in the policy. The possible results of this ambiguity would be biased resources flow to areas with abundant solar resources, while areas with less solar resources would have weak capability to utilize PV. These all influence functions market formation, resources mobilization and influence on the direction of search; in turn have an impact on the technological innovation system.

The second problem is weak organizational power. Though there are industry associations at national and provincial level, they are relatively weak. They have rare power in influencing policy and creating legitimacy for new technologies and technology utilization.

Another problem is about network. As it is stated before, networks between different actors are not well-developed. There is no direct material indicating close networks among firms. Connectivity between firms and research institutes is of varying quality; whereas large firms usually have cooperation with academia since most people in the board have studied abroad having access to foreign universities or research institutes with advanced technology, small firms are more inclined to achieve business success by low cost rather than by cooperation with academia to innovate technology due to high risk lying in innovation activity. Weak network among actors could lead to poor technology exchange and technology innovation ability.

Lack of skilled workers is also important in the industry development process, which is induced by lack of related education at universities. Education not only relates to technicians, but also people involved in this industry such as architects who are familiar with BIPV systems integrating PV system into building design.

According to the China Greentech Report 2011 (Hancock et al. 2011), the 12th Five-Year Plan (2011-2015) was released, showing the government's determination to promote renewable energy. It is regarded as China's most environmentally-focused plan to date. The plan also mandates that by 2015, 11.4% of the energy mix must come from non-fossil fuel sources. 5 GW of new solar power capacity is set as the target for 2015. And the solar power target is likely to be upwardly revised to 10 GW due to the desire to promote renewable energy in the aftermath of Japan's nuclear crisis.

To stimulate domestic market in the near future to enhance energy supply and improve environment quality, consistent and explicit supportive policies are required to attract investors and other resources. Long-term policies could show government's determination of promoting PV technology which is of central importance to reduce the risk inherent in innovation and deployment of an emerging technology. It is possible to encourage innovation by adding financial support to those who apply for new technology. Since silicon cells are still dominant in the Chinese PV industry, more financial supports could be given to those experimenting thin-film cells.

Weak organizational power and networks among actors should be enhanced to facilitate TIS evolution. Organizations such as industry associations could play a more powerful role to influence favorite policy making and to function as bridges between institutions and firms. And strong connectivity among actors is likely to create positive externalities for development by promoting collaboration between actors such as solar cells and module producers and inverter producers. This connectivity is likely to convey problems arising in practical PV systems more directly.

Though Chinese PV industry developed very fast in the past ten years, and a TIS pattern has formed after several decades, there are still problems unsolved to achieve success both in industry and domestic utilization. There is growth potential in PV sector to mitigate environment problems and energy crisis issues in China. And to achieve the growth potential, more efforts are required from government to firms to all other related actors.

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