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Master's Thesis

中國太陽光能行業轉變 – 由演化經濟面解決分析

China's Energy Transition to Solar Photovoltaic Energy – an Evolutionary Economics Approach

Student: Eran Navon

Advisor: Professor Leng Tse-Kang

中華民國一百年七月

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Abstract

China's growing energy needs have turned renewable energy into a crucial factor necessary for its social stability and national security. This paper has been written with the understanding that the role renewable energy plays in the Chinese industry and market will be nothing less than critical in coming decades. Solar PV electricity is one of the most promising renewable energy technologies and is a fast growing industry. However in China there exists a huge gap between its market potential and current achievements in the field.

This thesis paper depicts the evolutionary path China is currently undergoing from a heavy reliance on fossil produced energy to a balanced energy mix by examining its solar PV industry and market. Its major argument is that as transitional processes require long term vision and planning, the potential of china's energy transition to solar energy needs to be assessed under a set of criteria that can trace a long term development path. By using the six core elements introduced by the evolutionary economics theory, this paper presents a unique in depth analysis of China's transitional efforts toward solar PV grid parity.

The paper has reached three major conclusions. The first and most important is that the Chinese central government seems to be making genuine efforts in promoting solar PV as one of the nation's future energy sources. These efforts have been marked by assessing governmental legislation concerning Bounded Rationality issues and various incentive programs. The Renewable Energy Law and the Medium and Long-Term Development Plan have served as instrumental driving forces to the immature market. Local governments have shown significant commitment by providing substantial support to the PV industry as well to Co-evolutionary technologies such as inverters and batteries. Legislation has had limited success in handling Lock In issues such as connection to the national grid and real price reflection of conventional energy.

The second conclusion is that although the market is still at an early stage of its development, it relies too heavily on Selection promotions, namely direct subsidies. Recent developments in the PV market growth in China can mostly be regarded to the Golden Sun program and the BIPV program. These efforts have been an important promoter in raising global awareness to the potential of its solar sector. However this form of subsidy does not present a long term sustainable growth solution. The lack of a national Fid in Tariff scheme (despite few specific provincial schemes) and existing problems concerning projects tendering process cause an imbalance in terms of market and industry Diversity. This unbalance appears in the form of lack of Diversity in project developers, being mostly local state owned or highly affiliated with the government enterprises.

The third conclusion is that China's government can and should give more focus on domestic Innovation. Currently the country's national R&D investment is significantly lower than market leaders in Europe. China's education system does not support more than several world class solar PV electricity research centers and its industry development relies on expensive imported technology and international collaboration. Most companies in the industry hold a short term development vision which affects technological Diversity, mostly in the upstream segments of polysilicon and ingot production. Lack of attention towards a diverse range of future PV and Co-evolutionary technologies limits industry development to specific sectors that have low technological barriers.

The paper concludes that while China is well positioned for further expansion of its market it still lacks in specific aspects of its transitional path. This analysis is unique as it presents not only an up to date market and industry status but also refers to their future growth potential. This paper presents a wide range of aspects that directly affect solar PV's future development. Its true value lies within the usage of the evolutionary economics approach as a theoretical framework, which allows us to gain better understanding of how the different aspects related to the solar PV world affect each other and the fitness of this historic transition.

Acknowledgements

The idea of conducting research in the field of renewable energy came to me during the first weeks of my studies in IMBA. I would like to thank the program's professors who have each in their own way brought to my attention the importance and urgency of promoting clean energy. They have inspired me to further enhance my understanding of the challenges and needs concerning this historical transitional process. A special thank you goes to my advisor, Professor Leng Tse-Kang for his support and guidance throughout the project and for his comments and insights.

I would like to thank my family for showing the outmost confidence in me during my stay in Taiwan; my dad for proving to me that nothing is impossible, my mom for showing me that believing is everything, Shiri for teaching me about passion and Adi for helping me keep the right perspective on it all.

A big thank you goes to Brent and Avishai for their companionship and support, for turning every problem into a simple daily matter through a discussion over lunch or a drink in the park. One last special thank you goes to the members of T.E.A.M for helping me diminish the boundaries between dream and reality.

"Ring the bells that still can ring

forget your perfect offering

there is a crack in everything

that's how the light gets in"

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Introduction

Clean energy has been a rising star in the world of energy for well more than a decade. With awareness towards the threats of global warming on the rise, both public and private sectors have been enthusiastic on exploring a new world of technological possibilities. Global investment in clean energy reached USD 243 billion in 2010 alone, a thirty percent rise from 2009's USD 186.5 billion. (Renewable Energy World, 2011)

Among the different technologies, solar energy seemed to have always been underrated and underexploited. With the sun being the most fundamental form of energy it has been viewed by many generations as a potential savior from dependence on fossil fuels. Technological developments made in the last three decades have turned solar photovoltaic technology into a feasible commercial technology. As a result governments around the world have recently invested great resources in developing related technology, industry and infrastructure, with Germany, Spain and Italy acting as market leaders.

The discussion about clean energy should not be restricted to the developed world. Much of the mass of the global energy demand has shifted to developing countries such as the BRIC countries – Brazil, Russia, India and China. China has become a global concern in recent years as it has become the world's biggest consumer of electricity, and as such the world's leading country in fossil fuels consumption and green house gas emission. It has become a global priority to help China maintain its rapid economic development while pursuing a sustainable path for green energy.

This paper explores the potential of China's clean energy transition in regards to the solar photovoltaic sector. Its emerging market and industry has shown significant development in recent years and is expected to become a global market leader in the near future. The solar PV industry and market have indeed been regarded by government offices as a technological sector which holds the highest development priority. As such, significant funds have been allocated to encourage its development.

Transition to non fossil fuels should not be regarded as a common technological challenge. This process involves not only an efficient industry but also enthusiastic investors and developers. Creating a change from complete reliance on one form of energy production to another is no less than an evolutionary transition as it encompasses change in the entire energy production system. As will be shown below, PV technology is not yet a mature technology and cannot compete with conventional energy production methods. It requires the combined will and commitment of government agencies, research institutions, entrepreneurs and industry leaders if solar PV is to reach grid parity.

This paper presents an in depth analysis of China's efforts on transition to solar PV energy. Using an analytical framework derived from the field of evolutionary economics this research defines the strengths and weaknesses of China's transitional process. In order to depict a clear balanced picture of China's domestic market and industry the research combines a broad literature review from government agencies, international energy agencies, forums, academic articles, various blogs and news articles. Using the evolutionary economics model this research presents new perspectives and insights on the market and describes the path the sector is expected to go through in coming years.

Chapter one presents a literature review, describes the driving forces behind China's search for clean energy transition and presents the theoretical framework. Chapter two discusses barriers to developing renewable energy and solar PV as well as improving government efforts to overcome these obstacles. Chapter three provides an industry analysis and describes the industries effect on China's domestic market. Chapter four discusses the status of future technologies in the domestic market and the research and development barrier to sustainable transition. Chapter five concludes.

Chapter 1 - China's Transition to Clean Energy

In the past two years China has positioned itself as the world's largest manufacturer of solar panels with over 96% of its output designated for export. In 2009 alone Chinese manufacturers sold solar panels to Germany with a total power capacity exceeding 1 GW, which accounts to nearly half of the total capacity acquired in Germany that year.

There is a gap between China's flourishing solar industry and its nearly unexploited market. With an annual market of only 160 MW in 2009 and a total of 305 MW cumulative PV power installed by 2009, solar energy did not play a significant role in China's power generation mix until 2010. (EIA, 2010)

On September 8th 2009 Wu Bangguo, chairman of the standing committee of the National People's Congress of China, signed an agreement with 'First Solar' for a photovoltaic farm to be built in Ordos city, Inner Mongolia. In 2019, a 2,000 megawatt power plant will be built in what is expected to become the worlds' biggest photovoltaic project yet. The project will generate enough electricity to power around three million Chinese homes, with a total cost of up to USD 5 billion. Reports have announced that First Solar, the world's largest photovoltaic cell manufacturer, has thus 'cracked' the Chinese market. (New York Times, 2009) A project of this magnitude is considered a real breakthrough in the traditionally slow Chinese market.

1.1. Energy in China's Modern Economy

The gap between the PV market and industry can be explained by looking at the development policy and structure of China's modern economy.

China's transformation into market economy was initiated in 1978 shortly after Chairman Mao's death when its centrally planned economy gradually started to be replaced by a decentralization of policy implementation. With individual farming restored and the increase in productivity, labor required in agriculture was reduced and transferred to higher productivity jobs in the Township Village Enterprises (TVE). TVEs became the growth engine of the economy, reaching a peak in 1996 accounting for 26% of GDP.

Since the late 70s China has hurried to open up to foreign trade and investment in what proved to be a crucial element in its economic reforms. The successful establishment of the first special economic zones led to a proliferation of special zones and foreign trading companies licensed to contract with domestic enterprises. Exports expanded rapidly under these trade openings and by the late 1990s China became the second largest recipient of foreign direct investments. (OECD, 2009)

Capitalizing on its cheap labor force and rich natural resources the country has emerged as what is sometimes called the world's 'manufacturing hub'. It is therefore only natural for China to become involved with the PV production industry as it has done successfully with other sectors such as the automotive and fertilizers industries. However, it is the thermal and hydro industries which have been the fastest growing of all industrial sectors in China in the 90's and first half of the 2000's. This papers aim is to identify the significance of the solar PV industry in modern China and the driving forces and mechanisms behind it.

As noted, China's actual market for solar power is limited. We need to look at the country's power sector reforms in the past twenty years to gain a clear understanding of past barriers to the development of a significant renewable energy market.

With the industrial reform under way, an unsatisfied thirst for energy has been created within the transitional Chinese market. In only twenty years China's annual consumption of commercial energy has increased by over 800%. (Figure 1.1) It is now assumed that as of 2010 China has surpassed the United States to become the world's largest energy consumer.

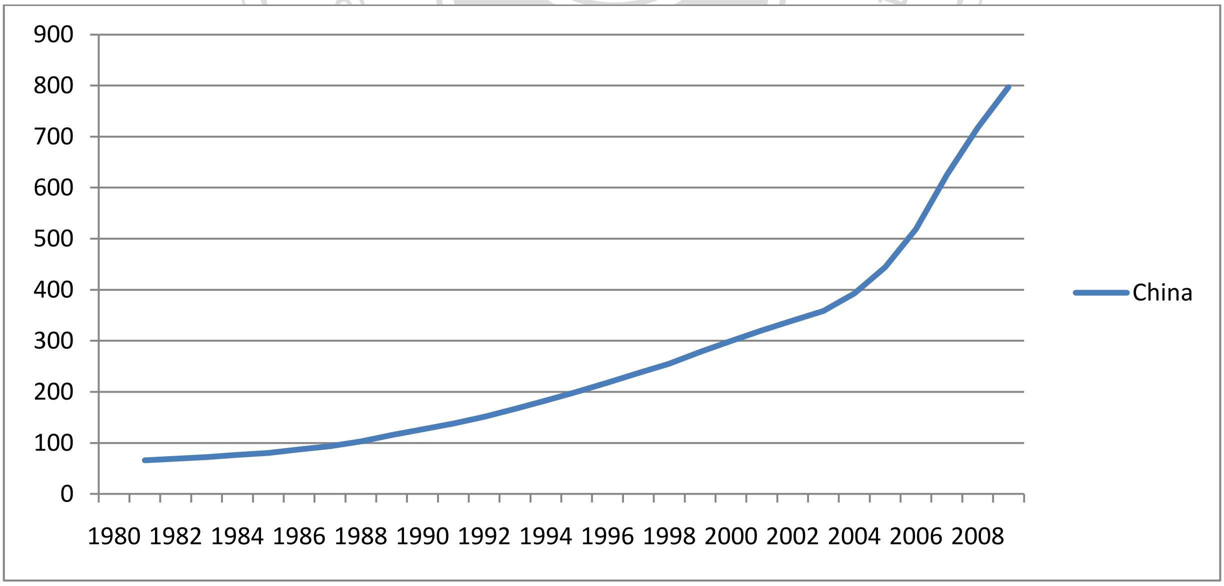


Figure 1.1 China's Annual Net Electricity Generation (GW)

Source: Energy Information Association (2011)
http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=7&cid=regions&syid=1980&eyid=2008&unit=MK

In 1993 China became a net oil importer as energy demand had, for the first time, exceeded domestic production. Since 1991 the nation has become the world's biggest producer of coal utilizing its abundant coal reserves, which rank third in the world. Coal had reached its peak contribution to the energy sector in the mid 90s averaging 75% of the total energy structure. Along with oil it makes up around 90% of its total energy mix.

Table 1.1 Structure of Primary Energy Consumption

	1980	1985	1990	1995	2000	2005	2010 (E)
Coal	72.2%	75.8%	76.2%	74.6%	66.6%	69.1%	71%
Oil	20.7%	17.1%	16.6%	17.5%	23.4%	21.0%	19%
Natural Gas	3.1%	2.2%	2.1%	1.8%	2.3%	2.8%	3%
Hydro, nuclear and renewables	4.0%	4.9%	5.1%	6.1%	6.7%	7.9%	7.2%

Source: Andrews-Speed (2004) Pg. 11. Energy Policy and Regulation in the People's Republic of China. (Hague: Kluwer Law Internationsl) and IEA, International Energy Statistics. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=7&cid=regions&syid=1980&eyid=2008&unit=MK last visited on July 17, 2011

While industrialization proceeded in fast motion, China's energy consumption had risen by over 80 % between 2002 and 2007. The continued success of its rapid economic growth has therefore become dependent on the parallel growth of its electricity sector. In order to improve the commercial and technical performance of the power sector the Chinese government has undertaken a series of reforms beginning in the late 90s. At the center of the reforms the government has attempted to separate the assets and operations of power generation from those of transmission and distribution, as has become the standard in developed markets.

In 2002 the government began to reform three main elements in the electric energy sector: (OEDC, 2009)

The restructuring of the State Power Corporation into five generating companies, two grid companies and a few other service companies, thus assuring a more equal distribution of assets and the privatization of major state owned generating capacity.

The restructuring of the sector's regulatory agencies, which included an increase in the number of regulating agencies, redistribution of functions and the creation of new functions. The most important of these measures was the creation of the State Electricity Regulatory Commission which reports directly to the State Council.

Adopting a new approach to market pricing and the development of competitive markets for power generation has been adopted in a few selected regions which included the creation of three different tariff systems for generation, transmission and distribution.

The main focus of these reforms was to supply the needs of the fast growing industry sector, although a significant increase of power demand in domestic households was also noted. The reforms targeted promotion of the existing coal market with a focus on price reduction and financial efficiency. All five big state power corporations did have a limited investment in hydro plants during the first years of the 21^{st} century, but a promotional framework for renewable energy was still missing. To sum up China's energy strategy in the years since the beginning of the reforms it is clear that the main focus has been towards simply increasing the production of energy.

1.2. Transition to Renewable Energy

This paper focuses on China's efforts to create a significant and sustainable renewable energy market with a specific focus on its solar energy market and industry. As we have seen above, the rapid development process which the country has undertaken has left little room for young advanced technologies to penetrate the market. 2004 however, saw the beginning of a gradual shift with environmental policy giving higher attention to energy efficiency and energy conservation. Starting that year the development of various forms of renewable energy has been receiving growing attention and significant efforts have been made towards promoting various new technologies.

The main reasons for which China has developed real interest in renewable energy falls under three main categories: energy security and optimization of the energy mix, environmental concerns and social and economical development goals for rural areas.

1.2.1. Energy Security and the Optimization of the Energy Mix

As mentioned above China has created a reliance on imported energy during the 90s when becoming a net importer of oil and gas. This situation has forced the country to spread its economic and diplomatic presence to wherever there is untapped supply. It has also led Beijing to pursue close diplomatic ties with countries that in many cases hold foreign policies that rival most developed countries. (Zha, 2006) Chinese companies have only a short history of dealing with the political risks of venturing into foreign markets and in some cases have been rejected and blocked from participating in development of oil fields.

As the world has experienced two oil crises within the last 50 years, the significance of developing a more self reliant energy market has become a priority. The list of possible reasons for the 2003-8 oil crises includes political tension in the Middle East as well as reports showing a decline in petroleum reserves and oil peak speculations. Middle Eastern countries have been and will likely continue to be China's largest source of energy. China's eagerness to develop relations with Middle Eastern countries has been the trigger for political conflicts with some EU countries and The US. An example for the challenges presented to China by maintaining good relations with its international oil suppliers is its relations with Iran, China's third biggest oil supplier, as its nuclear aspirations causing political tension between China and the US. (Liu et al, 2010)

Since the first major oil crises in 1973 governments have been continuously trying to assess the exact amount of exploitable petroleum reserves in order to estimate the maximum rate of global petroleum extraction. Based on the Hubbert peak theory (1956), once that point is reached petroleum production is expected to go into a constant stage of decrease. In 2010 the International Energy Association acknowledged that conventional crude oil production has peaked in 2006 and that gas production is expected to peak around 2035. (IEA, 2010[1]) With that in mind, countries around the world are preparing themselves for an efficient transition into a new energy consumption era.

Li and Woodrow have depicted (2010) the path China has gone through, from self reliance to market dependence. They claim that the new stage in its policy making calculations is the transition to green energy: "China's deep sense of its energy insecurity and vulnerability is changing its development policy towards clean and renewable energy... (it) is trying to rely primarily on domestic resources while strengthen mutually beneficial international energy cooperation." (pg 18)

1.2.2. Environmental Concerns and Climate Change

In July 2007 a report by the PLB Netherlands Environmental Assessment Agency declared that China has for the first time surpassed the USA to become the world's largest emitter of greenhouse gases. In the last two decades it has become a scientific consensus that global warming is an occurring phenomenon that is caused mostly by increased global greenhouse gas emissions, inflicted by human activities such as burning of fossil fuel and deforestation. Although the direct results of the world's climate crises are difficult to assess, likely effects are expected to be the rise of the sea level, flooding of many coastal cities, more frequent extreme weather events and the expansion of desertification processes.

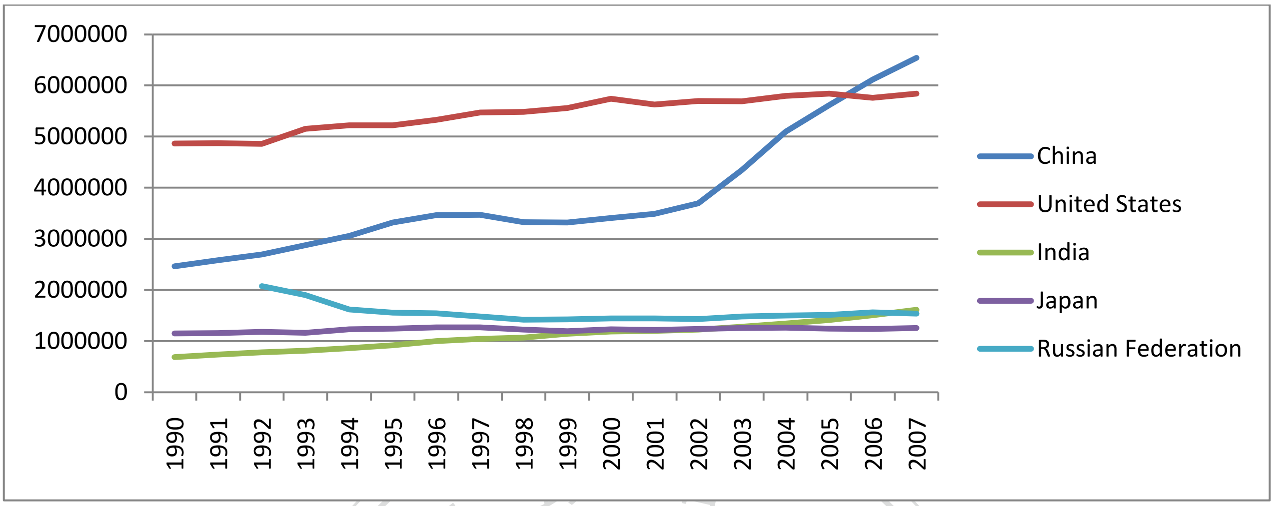


Figure 1.2 World's Five Largest CO2 Emitters (thousand metric tons of CO2)

Source: United Nations Statistics Division (2011)
http://mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid= last visited on March 4, 2011

As shown in figure 1.2 China's CO2 emissions have almost doubled within a span of five years, jumping from 3,684 metric tons CDIAC in 2002 to 6,538 in 2007 and 7,706 in 2009. China holds about a quarter of global CO2 emissions and has been accounted for two thirds of the 2007 global carbon emission increase of 3.1%. (PLB, 2008) The EIA 2010 forecast and analysis has predicted that China's share of the total global emissions is expected to continue increasing and reach 31% by the end of 2035. (EIA database)

With climate change receiving unprecedented attention in recent years China has been experiencing growing criticism from the international community concerning the environmental price claimed by its rapid economic growth. Much of that criticism addresses the extent to which China should take measures to reduce its CO2 emissions. It has been shown that economic development in the past two centuries has gone hand in hand with the deterioration of the ecological system as a result of environmental unfriendly technologies. It is therefore a great challenge for China and other developing economies to ensure similar rates of GDP growth along with transition to greener technologies. It is important to mention in this context that although China is the world's largest emitter, its emission per capita still measures below the world average.

Chinese leadership is aware of this environmental challenge and in 2007 the National Development and Reform Committee (NDRC) has came up with a national climate change program. The paper provides key policies and measures to be approached directly by the government. The optimization of the energy mix by developing renewable energy is of course listed under efforts to mitigate climate change but interesting enough it came only second behind efforts to improve traditional energy efficiency. Through the discussion on solar energy markets in China this paper will treat the challenges of transition from existing technologies of energy production to new advanced technologies.

1.2.3. Social and Economic Development Goals for Rural Areas

China, more than any other country, represents the trend of urbanization and expansion of urban industrial service sector in the expense of rural areas. China's rural society is estimated at around 55% of the total population, a rapid decrease from an estimated 98% in the early days of the PRC. It has been indicated by Chinese leaders that the rising gap between mostly rich urban and mostly poor rural citizens is one of the most serious challenges for modern china today. Whereas a small number of coastal provinces and the special development zones in south eastern China can be mostly attributed to China's growth rate, many regions have lagged behind.

In order to initiate a more rapid development of rural hinterland, the central government has taken three leading measures: liberalization of the land tenure system in order to protect land owners from land rights extortion; a more pragmatic rural-urban migration and hukou system of household registration in order to better canalize human resources; a large scale infrastructure project which includes railways, water channels, reservoirs, roads and electrification projects. (Heilig, 2003)

Within the span of 50 years, China has increased the population with access to electricity from roughly 40% in the 50's to 95% in 2004. This however leaves 9 to 22 million people in remote areas without access to electricity. (To, 2009) In areas where connection to the main electricity grid is not viable China focuses its efforts on renewable energy projects. Unlike the National level in which energy generation heavily relies on coal, local generation in china's rural areas has been dominated by small hydro projects which amounts to over half the production. The next most common energy production form is thermal power which plays an important role in ensuring stable supply. In order to promote sustainable development that is both economically viable and socially acceptable authorities are pursuing for measures that will be less destructive towards the environment. Renewable energy is expected to play a key factor in assuring sustained utilization of natural resources for generations to come.

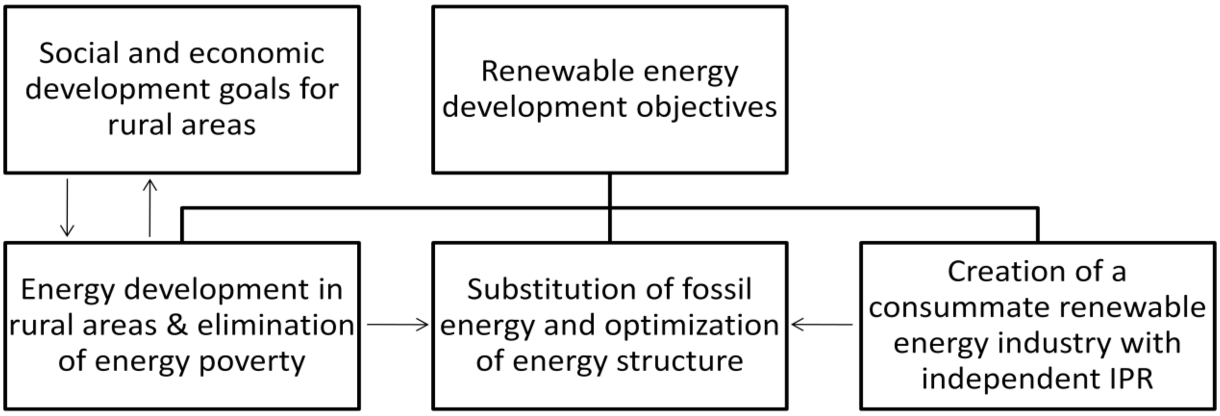


Figure 1.3 Components of China's Renewable Energy Development Objectives and Correlations

Source: Shi Dan, 2010 China's Renewable Energy Development Targets and Implementation Effect Analysis, in *The Globalization of Energy: China and the European Union*, pg. 204. ed. M. Parvizi Amineh and Yang Guang. (Leiden: Koninklijke Brill NV)

The substitution of fossil energy and optimization of energy structure is a goal shared by all countries. China perceives that the establishment of a renewable energy industry is a must if it wishes to protect its national interests within the global competition in renewable energy development. As shown in figure 1.3 below, energy development in rural areas and the creation of a renewable energy industry have a supportive relation to the main goal, which is substitution of fossil energy and the optimization of energy structure.

1.3. Introducing Solar Energy

Since ancient times men has tried harnessing the sun for its own usage. The sun has been used as far as the 7th century BC as a tool for making fire using a magnifying glass to concentrate sun rays. The photovoltaic effect was discovered by Edmond Becquerel in 1839 while experimenting with the effect of exposure to light on electricity generation using two metal electrodes placed in an electricity conducting solution. The word photovoltaic is derived from the word photon, meaning light, and volt, meaning unit of electric potential and refers to the conversion of sunlight into electricity.

Like all renewable technologies, there are pros and cons to solar PV systems. Unlike hydropower systems, generating energy from the sun is limited to fixed daily intervals whereas during night time energy needs to be extracted from an alternative energy source or from a battery backup system.

Solar panels require a large area of installation that cannot be used otherwise for agriculture, unlike wind harvesting farms. Its greatest disadvantage is the initial cost of installing a solar energy system mainly because of the high price of semi-conducting materials.

Using solar to produce electricity does have some significant advantages. There is more than enough solar irradiation available to satisfy the world's energy demands. Each square meter of land on earth is exposed on average to enough sunlight to generate 1700 kWh of energy every year, 10,000 times more than the existing global energy needs. Only a small percentage of this potential can be tapped with today's existing technology, however unlike fossil fuels there is no issue of finite resource wastage.

Moreover, PV modules can be used for around 25 years, which after can be recycled and re-used under appropriate treatment. Unlike hydropower dams than have a significant negative environmental impact on surrounding ecological systems, solar power systems keep their affect to a minimum. PV systems are easy to install, are reliable and recoup the energy spent on their creation within a short time span (6 months to 3 years). (EPIA, 2011[1])

40 years separate the first basic PV applications which were used in space and the GW systems which are being used today. PV technology has become in the last couple of years a major source of world power generation. From 16 GW of cumulative installed PV capacity at the end of 2008, capacity has grown to 23 GW and almost 40 GW in 2009 and 2010 (120% annual growth in 2010 alone). This major increase is directly linked to the rapid growth of the German market in 2010 (7.4 GW) as well as the Italian market (2.3 GW). It is no surprise therefore to find the EU as the leader with 30 GW installed capacity, accounting for around 75% of the total global market. Outside the EU, Japan and the USA have a developing market as well with 3.6 and 2.5 GW of installed capacity. (EPIA, 2011[2])

Despite these significant accomplishments, PV electricity still constitutes only 0.2% of the world power consumption. It trails hydropower which holds 15% of global capacity and constitutes over 80% of the total renewable power capacity. Apart from hydropower, wind power is the only other significant grid connected renewable technology with over 160 GW installed by 2010 but still less than a single percentage of total capacity. (REN21, 2010) Aside from grid connected technologies, biomass heating and solar hot water heating technologies are other renewable based technologies that are commercially used around the world.

As mentioned above, the cost of PV systems has been the main obstacle to its technology's evolution. The competitiveness of the industry relies on its ability to reach grid parity, defined as the “moment in time when the savings in electricity cost and/or the revenues generated by selling electricity on the market are equal to or higher than the long-term cost of installing and financing a PV system”. (EPIA, 2011[1]) This paper aims at analyzing and asserting the PV industry and market in China. Using an analytical framework taken from the European Photovoltaic Industry association (EPIA) under an evolutionary economics framework of analysis, this paper will evaluate the progress made in China in recent years and the future of its PV electricity sector.

1.4. Analytical Framework

The European Photovoltaic Industry Association (EPIA) is the world’s largest industry association devoted to exploring the solar PV electricity industry and market. In their 2011 industry report the organization has set several criteria for the achievement of price competitiveness of PV, factors affecting PV systems cost reduction and issues concerning the integration of systems into the energy markets. This paper will discuss the current status of china’s solar industry in regard to the elements mentioned below.

1.4.1. Price Competitiveness of PV

Module price – In general PV module prices have reduced by 22% each time the cumulative installed capacity has doubled. This is mostly the result of the industry gaining economies of scale and experience. Innovation, research, development and political support have been the major drivers to price cuts.

System price – While modules take the greater part of the price of a complete system, other components, referred to as Balance of System (BOS) components, are also to be considered. These elements such as inverters, wiring switches etc. have had more volatile pricing. BOS has also shown a constant decrease in price with the increase of cumulative installed capacity.

Electricity generation cost – The Levelised Cost of Electricity (LCOE) compares the profitability of different power generation plants according to their investment and operational costs of a system’s life time. As expected, electricity generation is more expensive (per kWh) in areas that have less exposure to irradiation such as northern Europe than in the Middle East. LCOE is a common tool in comparing renewable energy systems to other conventional electricity producing systems such as gas and nuclear production.

Electricity price evolution – With conventional electricity being subsidized in many countries by governments, conventional prices do not reflect actual production costs. Government support is therefore a key component of the success of solar PV. Moreover, as the current market price of CO2 emissions is considered to be below its realistic price, any investment which is made now in renewable energy will be paid in the future with prices rising. Above all, as PV is already becoming competitive in countries that have high sun irradiation, it is expected to become more competitive as prices of conventional energy resources increase.

Market segments – Off grid applications are already cost competitive compared to diesel generators. Grid connected applications are not yet competitive, however research has shown that in some countries both large utility scale PV systems and systems for the residential segment are already competitive during summer or winter peak demand.

1.4.2. PV Cost Reduction

Technological innovation – This aspect mainly refers to efficiency. More efficient PV modules less raw material, less manufacturing energy and lower the BOS costs. Other than that, the PV sector is trying to replace toxic and scarce materials with common environmentally friendly materials.

Production optimization – As companies scale-up production, they use more automation and larger line capacities. Improved production processes can also reduce wafer breakage and line downtime.

Economies of scale – Economies of scale can be achieved at the following supply and production stages: bulk buying of raw materials, obtaining more favorable interest rates for financing, efficient marketing.

Extended life of systems – 25 years is considered the minimum lifetime of a PV module. With research being made in the encapsulating material field, systems are expected to reach lifetime of 40 years.

Development of standards and specifications – Standards and consistent technological specifications help manufacturers work towards common goals and contribute to costs reduction in design production and development.

Next generation technologies – Here lies the greatest potential in cost reduction. Today's main research fields are on increasing stability over time and increasing the solar cell area.

1.4.3. Integration of Systems Into the Energy Markets

High penetration of PV in the grids – With small amounts of PV connected to the grid, most of the electricity produced is consumed at the site or in the immediate neighborhood. Studies show that PV could account for up to 20% of supply without affecting the grid, after which broad technical development will have to be made. Also, since PV depends on the sun it is variable and needs to be balanced by other sources of power. Although irradiation prediction is quite accurate and much easier than wind forecasts it still remains a challenge, especially on a small scale.

From centralized to decentralized energy generation – Many countries are now starting an evolutionary process of moving from a mainly centralized electricity generation to a decentralized form. However as electricity grid operators need to rethink how to guarantee the quality of electricity delivery some areas need to be further improved and developed. The major areas concerned are peak load shaving, global management of the super grid to better capitalize on the natural resources of greater areas, transition to more efficient smart grids, storage and demand management.

1.5. Theoretical Background – Evolutionary Economics

As mentioned above, transition to alternative sources of energy consumption cannot be achieved over night and requires comprehensive changes within a variety of elements within the industry and market. This paper will approach the issue of China's transition to PV electricity usage from the perspective of evolutionary economics. The significance of the usage of the word 'transition' as in contrast to 'change' is that this term links up with the notion of sustainable development and shifts the attention to the process itself as a more concrete step.

Transitions can be described as either spontaneous or goal oriented as well as by their degree of complexity. Spontaneous transition all hold a major degree of complexity and include the invention and use of fire, the rise of agriculture and the industrial revolution. These transitions have not been planned in advance and have been impossible to predict. Intermediate kinds of transition would be electrification and transitions in transport, from horse and wagon to cars for example. The green revolution is a considered a minor transition, the only kind of transitions that are goal oriented. The strive for a minor transition compensates for major transitions being out of the reach of public regulation by man.

The term evolutionary economics was first used by Thorstein Veblen in 1898, but it was Joseph Schumpter that became the first influential of evolutionary economics. Schumpeter showed a great interest in the dynamics of economics and considered qualitative economic and technical change in a wider context of social change. He used the term creative destruction to describe a process in which revolutionary forces from within the economy destroy old processes and create new ones. This process of change follows a major invention that encourages the formation of clusters of derived innovation.

In 1982 Richard Nelson and Sidney Winter have published “An Evolutionary theory of Economic change”, which has become the most influential text dealing with evolutionary transition in economics. This publication deploys the three core Darwinian principles, variety, inheritance and selection, which make the building blocks of their theory. In this text Nelson and winter claim that as changes continuously occurs in technology and routines, the mechanisms that provide these three elements need to be identified and structured.

Based on this and other works in the field of evolutionary economics, Jeroen van den Bergh and Frans Oosterhuis from the institute of environmental studies of the Free University in the Netherlands have introduced six core concepts of evolutionary economics. These concepts are Bounded Rationality, Diversity, Innovation, Selection, Path Dependence and Lock In and Co-Evolution. These six concepts will be used in this paper as guidelines in assessing the process of structural change taking place in China’s PV industry and market.

An overview of each concept will be provided first: (van den Bergh and Oosterhuis, 2008)

Bounded Rationality

Bounded rationality replaces the traditional neoclassical assumption of rational and optimizing behavior. This implies that agents are not fully informed and will not include all possibilities in their considerations for performing any behavioral or economic act. Gathering complete set of information is constrained by time and energy and therefore agents are inclined to rely on routines, heuristics and imitation. A satisfactory decision is often as good as or better than a perfect decision in terms of costs related to achieving a solution. Bounded rationality therefore takes the form of routines, habits, imitation and limited time horizon. As will be shown below, in the capital intensive market of PV the short time horizon of investors plays a major role. PV projects’ financial performance is highly dependent on the discount rates or payback period applied by investors.

Diversity

Diversity or heterogeneity in strategies of an economic agent is a consequence of bounded rationality. It is a central concept in the evolutionary framework as it is regarded as a measure for the flexibility and evolutionary potential of an economic system (also referred to as fitness). Diversity relates to economic strategies, technologies, knowledge, agents and institutions. It can be categorized by the number of options on a portfolio, the evenness of representation of the different options and the degree to which the options differ one from the other. Diversity is high in the PV electricity world as companies dealing with PV technology display a large variety in size and type of industry. A range of technologies exist and within a wide range of applicative areas.

Innovation

Innovation and selection are two concepts that influence diversity directly. Innovation implies an increase in opportunities for creative combinations that contribute to the system's survival and fitness. Innovation is often the result of serendipity, the combination of insight and expertise with chance. Knowledge and systematic search are the two methods in which the chances for innovative combinations can occur. Incremental innovation refers to improving the performance of existing technologies whereas radical innovation usually involves the combination of very different concepts and technologies. Serendipity, cross fertilization and niche markets have played an important role in the development of PV so far, although the lack of a coherent future perspective on the role of PV technology has been a restraining factor up until the second half of the last decade.

Selection

Selection is a process that reduces diversity. It refers to the survival and reproduction of successful agents or strategies in a system. Selection environments are complex, with technological, organizational, economic and institutional dimensions. It is difficult to plan and forecast transition in such an environment, especially since each kind of economic evolution has its own unique environment. PV is still an expensive technology, as mentioned above, therefore is dependent on subsidies and other preferential policy measures. As will be shown below, governmental policies play a crucial role in the selection process of PV.

Path Dependence and Lock-in

Repeated selections causes changes in the population systems. This can occur because of scale advantages, imitation or bandwagon demand side effects, technological interrelatedness or complementarities etc. In competition against technologies whoever gets a larger market share first will have an advantage and could grow relatively quicker. Increasing returns can give rise to the dominance of a particular technological or economic regime that does not let other (efficient and inefficient) technologies arise – these dominant technologies are called a lock-in. Other systems outside the lock-in look irregular and lack repetition, and therefore are considered as path dependent - adaptations need to be made before they are cumulated. Since technology tends to follow irreversible pathways it requires a major effort to shift away from lock-ins and promote path dependence technologies. PV systems hardly benefit from economies of scale and are suitable for systems of decentralized electricity supply. It is a great challenge to fit the grid system for this kind of technology.

Co-evolution

This concept refers to the mutual influence and interference between two or more systems or populations. The pressure exerted by one system over the other leads to related evolutionary developments. Co-Evolution is thus a particular concept of dynamic interaction between two populations with internal diversity. Solar PV technology, having an intermittent character due to fluctuations in solar energy influx, will have implications for other components of the energy system such as energy storage devices. Solar PV technology also requires development in other BOS components that are technologies shared with other fields such as inverters and smart grid.

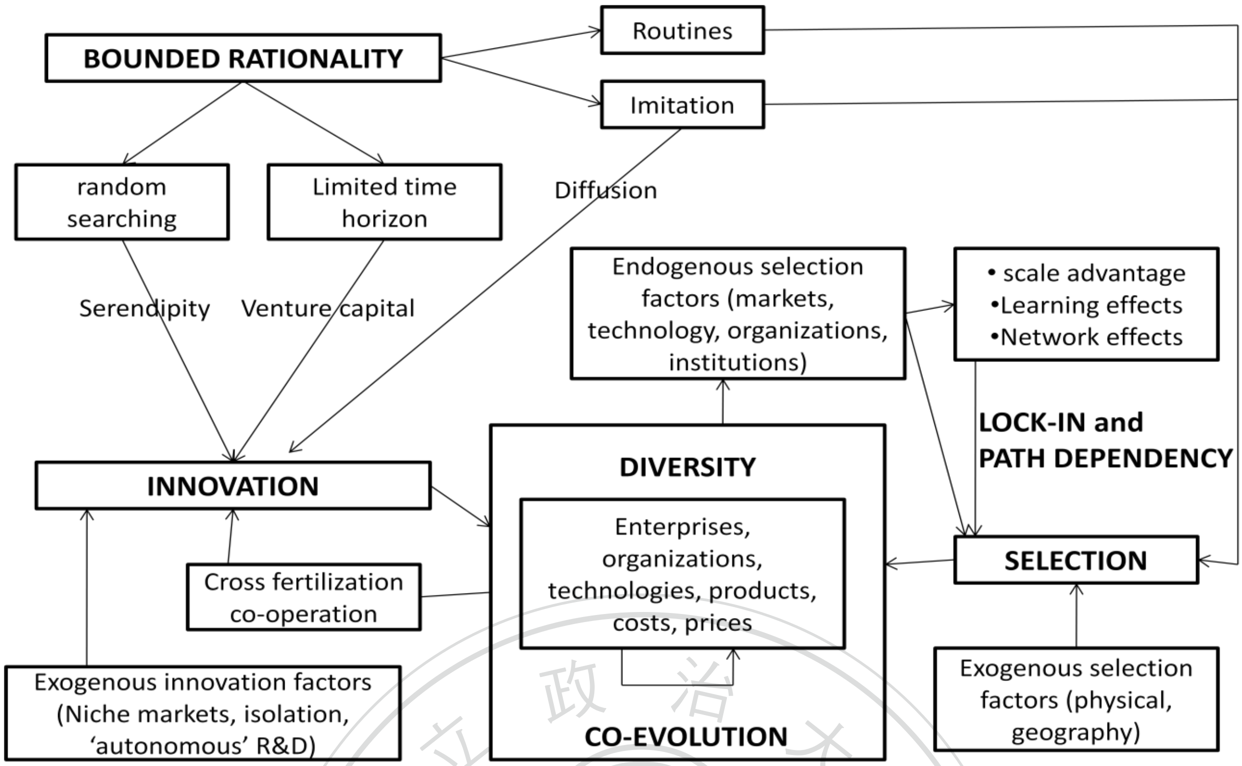


Figure 1.4 A Schematic Representation of the Evolutionary Economy

Source: Jeroen van den Bergh and Frans Oosterhuis, 2008. An Evolutionary-Economic Analysis of Energy Transitions, in *Managing the Transition to renewable Energy: Theory and Practice from Local, Regional and Macro Perspectives*. Pg. 149-173. Ed. By Jeroen C.J.M. van den Bergh and Frank R. Bruinsma. (Great Britain: MPG Books LTD)

1.6. Hypothesis

As shown above, the success of achieving a balanced economic transition depends on a variety of variables, some which are beyond the direct influence of stakeholders and policy makers. As transition is a long process that does not begin at a specific point in time and end at another, a criteria needs to be set in order to define whether the process of transition is advancing in the desired direction.

This paper regards to PV grid parity in China as criteria of success. PV has not yet reached grid parity anywhere in the world, although the EPIA 2010 annual report has shown great optimism in reaching that goal in some countries within the coming decade. According to the evolutionary economy theory, all six elements mentioned above need to be balanced and well positioned in order to allow transition to take place.

The hypothesis of this paper is therefore: Bounded Rationality, Diversity, Innovation, Selection, Path Dependent and Lock-In and Co-Evolution need to be balanced and well positioned in order to promote solar PV grid parity in China. Although the greater part of the discussion will relate directly to these elements as they appear in china, one cannot separate them from the international PV industry and market and therefore they will also be mentioned during the analysis.

The uniqueness of Van den Bergh and Oosterhuis's schematic representation is that it places the six evolutionary elements in a relative correspondence. The assessment of not only each element's features within a process but also the way they effect each other makes the evolutionary approach a well balanced tool. The interaction between the elements plays a more important role than the elements do alone, and is a key component to the success of the evolutionary process.

A large amount of researches and reports have been written concerning China's solar PV efforts in the past few years. Some of the reports have been mostly informative, depicting trends and events in the industry and market. The European Photovoltaic Industry Association and International Energy Agency have both prepared an in depth analysis on China's market which are highly informative. More specific papers have been written concerning specific aspects of China's solar PV sector such as Tour et al's analysis on innovation and technology transfer or Chen's analysis on the development of solar PV as a niche market. (Chen, 2008) Governmental reports have either given an in depth description on the industry (REDP, 2008) or the market and government incentives (CTCREP, 2009) with little analytical integration.

This paper was written in an attempt to integrate two elements. First, it aims at introducing the relationship between the Chinese PV market and industry. As mentioned above there is currently a huge potential gap between the current market and its potential expansion. This paper will show that both the PV industry and market have direct influence on each other's development and mutual dependant for future success.

Secondly, this paper will present an in depth analysis of the relationship of the government with the industry and market players. As almost every aspect of business and industry in China one must understand the role played by the central government, as well as provincial and municipal governments. The paper relies on existing information found in current literature as well as news articles various company websites and data bases.

Using the evolutionary economics theory, this paper provides a unique analysis of the interaction between government, market and industry and assesses the extent to which China has positioned itself to carry out an energy transition to solar electricity in coming years and decades. Having set a clear goal in the form of grid parity and a specific list of bench marks, this paper can serve as a practical tool for decision makers and investors looking for business opportunities in the Chinese market.

Chapter 2 - Government Policy

Government policy has served as a key component in promoting renewable energy technology since before the 1990's. (Loiter and Norberg-Bohm) Like many countries, China uses fiscal support as a tool to promote renewable energy deployment. As mentioned above, the development of PV technology and market is heavily dependent on government incentives and subsidies in order to develope. This chapter will analyze the role of the government in promoting a sustainable transition in China's electricity market. The chapter will focus on past barriers to transition, the range and efficiency of laws and regulations, incentive programs and present transitional challenges.

The role China's central government plays in promoting the PV market can be best seen in the relationships between two concepts: Bounded Rationality and Selection. This chapter will focus on the different instruments which have been put in effect in the last decade in order to promote solar PV in the grid electricity market. As will be shown below, Bounded Rationality is a key factor which prevents the Chinese PV market from fulfilling its potential. Significant efforts have been made in recent years in order to foster a balanced Selection environment that will promote the market in a sustainable transition path.

2.1. Exogenous and Endogenous Selection Factors

In terms of exogenous selection factors, selecting a path to solar energy utilization is nothing less than expected of China, as it has abundant solar radiation resources. Average daily radiation in many areas in China exceeds 4 kWh/m^2 and the total annual radiation it receives equals to 1.7 trillion tons of coal, more than 700 time its current annual consumption. Areas which are richest in radiation are Tibet, Xinjiang, Inner Mongolia and Qinghai provinces which together account for over 50% of China's solar sources. (CTCREP, 2009)

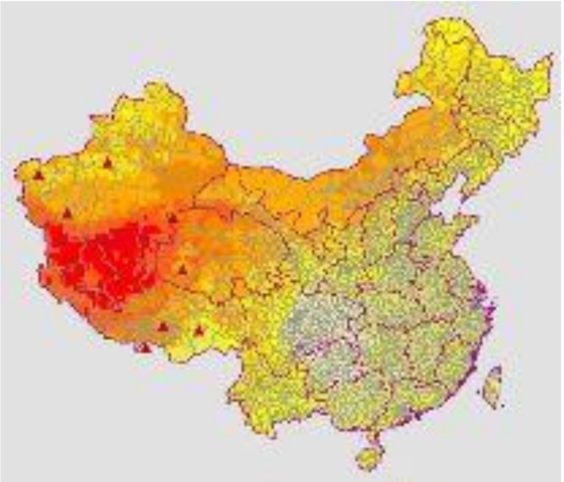


Figure 2.1 Solar Energy Resources Distribution in China

Source: Cleanergy September 9th, 2009. Huge Solar Power Plant in China – first solar and Chinese Government MOU. http://cleanergy.blogspot.com/2009/09/fwd-huge-solar-power-plant-in-china.html visited on May 27, 2011

China's endogenous selection factors are however unique and play a significant role in its energy transition efforts. The most radiation abundant regions are located in China's north west which is significantly less developed then the costal rich eastern provinces. Although these regions contain vast unutilized land resources they are mostly rural and are a great distance away from the country's central grid. Most of china's PV manufacturing is done in developed provinces which are mostly located in the eastern coastal region and it is a current challenge for the central government to breach the gap between these two sides of the country.

2.2. Early Renewable Policy

Chinese renewable energy policy has entered an advanced phase in 2005 with the issuance of the national Renewable Energy Law (REL). This law serves as an umbrella framework for developing renewable energy whereas specific regulations and measures followed in order to support the development of specific sectors such as wind, solar and biomass energy sources.

Prior to the adoption of the REL few laws have been passed which encouraged the development and utility of clean energy. (REN21, 2009) China's first successful application of solar cells was on the "No. 2 East Red Satellite" in 1971. However due to the technology's high price, terrestrial use was very limited until the 6th and 7th five year plans (1981-1990) under which the government started to support a wider use of. (REDP, 2008)

The 1995 Electricity Law was enacted to promote the development of the electric power industry and protect the industry's stakeholders. Two years later the Energy Conservation Law was embedded, providing preliminary tools for facilitation of energy savings and improving economic benefits of energy use. The Law for Prevention and Control of Air pollution was passed in 2000 with a goal of prevention and control of atmospheric pollution. Backed up by these general legislative efforts, some more concrete measures have been taken in the renewable and PV sector PV technology started to be applied in special industries such as the military as well as for operation of household systems and power supply systems in rural villages.

In 2001 the NDRC launched the Township Electrification program in an attempt to solve power supply problems in isolated rural areas. In just 20 months, the program electrified more than 1,000 townships in nine western provinces. This project has brought power to nearly one million people and is considered as China's first major electrification project using renewable energy. Out of a total of 221 MW of installed capacity 20 came from deployment of PV systems, with the bulk of the energy produced using hydropower systems. The government has provided USD 240 million to subsidize the capital costs of equipment. (NREL, 2004[1])

Programs smaller in scope and scale in which PV played a significant role have been launched since. The "Sunlight program" which has run up until 2010 attempted to establish large scale grid connected PV projects, PV/hybrid village power demonstration systems and home PV projects for remote areas. However due to inefficient financing regulations and lack of concrete goals it did not play an important role in promoting the market.

Two more notable programs have been implemented by the NDRC. The "Brightness Program" instituted multilateral assistance to install several solar and wind systems in North West china. The "Ride the Wind" program supported the development of domestic manufacturing of wind turbine components. (NREL, 2004[2])

China's commitment to growing its renewable energy industry is best shown at the Bonn Renewable Energy Conference in 2004 where it has first declared that it will commit to generate 10% of its electricity from renewable by 2010:

Renewable energy is the ultimate way to solve the problems of energy resources and environment faced by humankind at present… The Chinese Government highly values the development and application of renewable energy… In order to accelerate the development and application of renewable energy, China is setting about formulating the China Renewable

Energy Development and Utilization Promotion Law… We hope to promote the commercial and scalable development of renewable energy in order to realize the common progress of the entire human race and to promote the sustainable development of society together with all countries all over the world. (Zhang Guobao, Vice president of NDCR, Cherni and Kentish, 2007. Pg. 3620)

2.3. Barriers to Renewable Energy

Three main elements have been identified as overall barriers to promoting renewable energy in China. These elements are institutional barriers, cost of renewable energy and connection to grid.

2.3.1. Institutional Barriers

It is evident that the Chinese government is interested in playing an active role in the Selection element of renewable energy in general and PV technology in particular. The 2005 REL has been the result of this willingness and was aimed at overcoming institutional barriers that interfered with renewable energy industry development. Some of the barriers given most attention at the time were:

Import tariff reduction for complete equipment – Since 1996, general average customs rate has been reduced by 23% with wind turbines and PV equipment treated preferentially. Criticism has been raised concerning this incentive as it damaged local industry with developers saving costs by importing components. While the wind power developers enjoyed a 3% tariff rate and no import tax which had a strong negative effect of the local industry, PV developers had to add 12% tax on their imported components at the time. (Development Research Center, 2002)

Few government low interest loans – Up until 1994 energy conservation infrastructure projects received low interest loans that were 30% lower on average than interest on commercial loans. However after the reform of the financial and tax systems these favorable interest rates were eliminated with another low interest loan program terminated in 1997. (Development Research Center, 2002)

Foreign loans and lack of international and local financing mechanisms – With an industry that lags behind international standards, developers rely heavily on foreign grants and loans. These usually are tied to purchase obligations of donor country generation equipment which keeps the local Chinese industry at the same status. In general there has been a lack of domestic and international financing channels and mechanisms which left the renewable energy sector with insufficient capital. (Cherni and Kentish, 2007)

All three barriers are a result of a policy which focuses on the Selection and Bounded Rationality elements. The main driver behind them is the need to reduce the high cost of renewable energy, which mostly results from the undeveloped industry and lack of financing mechanisms, and attract developers to a market that does not offer immediate returns. However, these policies have damaged the local industry's Innovation and Diversity as they created over dependence on a limited range of local and foreign agents and significantly limit venture capital in local projects.

2.3.2. Renewable Energy Cost

The greatest barrier for renewable energy in China is its high cost in comparison to coal fired generation. China strives to keep electricity prices low in support of its GDP, however this goal conflicts with renewable energy promotion. Weak pollution controls fail to reflect the real economical price paid with the growth of CO2 emissions. Moreover China had many old coal fired generation plants which have fully depreciated their capital cost and are less capital intensive than renewable projects.

This is an example of the Lock-In condition the renewable market is facing while trying to compete with the current dominant electricity industry. Coal fired plants are expected to have the upper hand for years to come and it will require great calculated efforts in order to shift away from the current energy producing model.

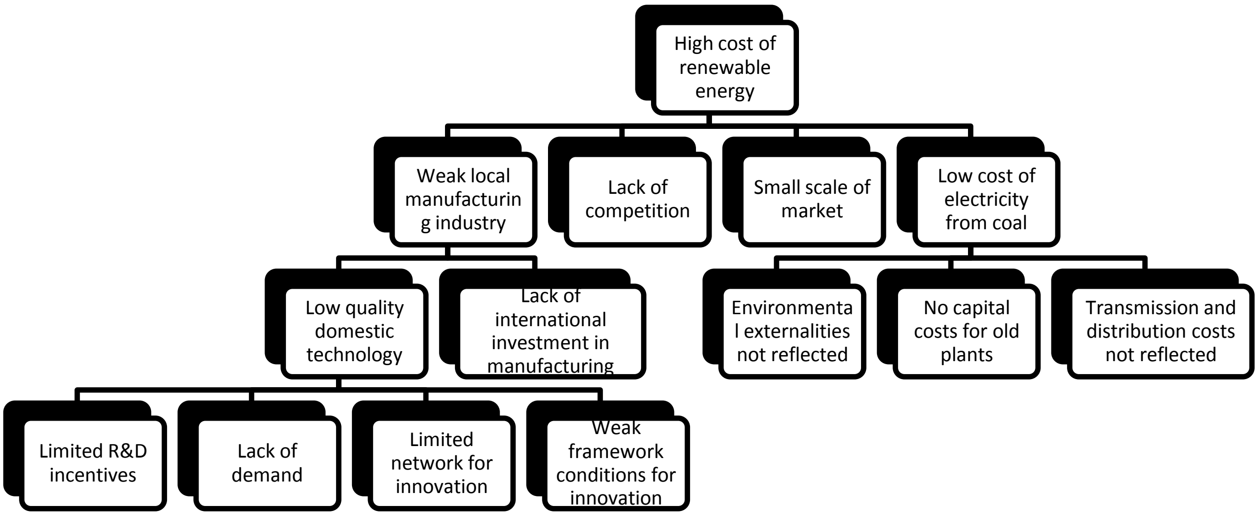


Figure 2.2 Factors Contributing to the High Cost of Renewable Energy in China in 2004

Source: Cherni A. Judith and Kentish Joanna, 2007. Renewable energy Policy and Electricity Market Reforms in China. *Energy Policy*, 35 (2007) pg. 3616-3629

Another factor which contributed to renewable energy's high cost was China's weak local manufacturing industry. The lack of R&D incentives and demand limited networks for innovation and the lack of framework for innovation have all caused domestic technology to remain low in quality which further weakened the local manufacturing industry. The lack of substantial market demand and fixed price guarantees has also discouraged international manufacturers from investing in the local industry. Chapter 3 will focus on the Chinese PV industry and on the ways it relates to the concept of Diversity.

2.3.3. Connection to the Grid

More barriers to renewable energy can be found at the connection of renewable projects to the national grid. These barriers mostly originated as a result of lack of cooperation and conflict of interest between developers and grid operators. In 1994 the Ministry of Electric Power issued a regulation which required provincial electric grid authorities to connect wind farms with nearby power grids and purchase all generated electricity. A similar regulation has not been issued for solar PV powered projects as most of PV projects at the time were for rural off grid application.

However, the regulations failed to work in practice due to a number of barriers. Grid companies found it difficult to gain government approval for the increase in their sales price due to high cost of production. They were also reluctant to share the costs of renewable energy projects connected to other parts of the grid which led to failures of a number of projects. On the technical side, many parts of the grid were too weak to dispatch intermittent renewable energy. In other cases developers either experienced bottle necks which prevented the energy from dispatching or found that the grid needed an expansion which the grid company refused to pay for. In addition, small scale generators have found it impossible to gain approval to connect to the grid

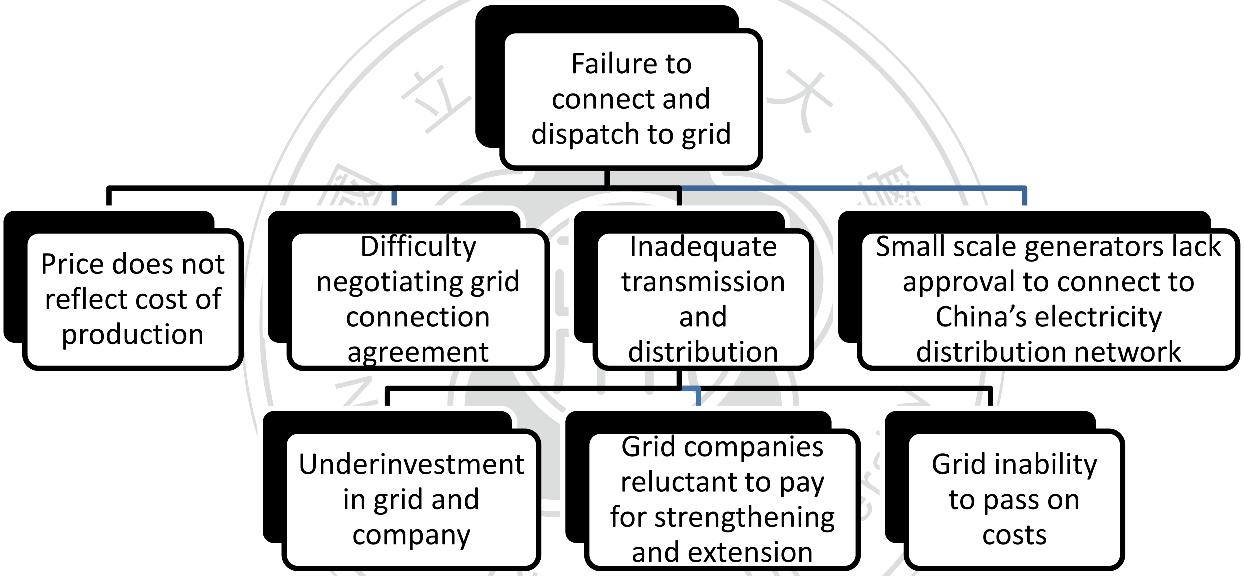


Figure 2.3 Barriers that Prevent Renewable Sources of Electricity from Connecting to the Grid in 2004

Source: Cherni A. Judith and Kentish Joanna, 2007. Renewable energy Policy and Electricity Market Reforms in China. *Energy Policy*, 35 (2007) pg. 3616-3629

2.4. The Renewable Energy Law

The REL came into effect on January 1st 2006 with a clear design to address barriers to renewable energy and to facilitate the growth of the industry. Some specific policies and mechanisms were introduced as a part of these efforts. As a primary means to ensure that renewable energy projects recover their operation costs the REL set up guaranteed grid access and cross subsidization. Enterprises that operate electricity grids (mostly the State Power Grid and the China South Power Grid) will purchase all grid connected generated electricity from approved renewable electricity generators. The price of purchase will not be decided by the market but will follow government guided prices. (Renewable Energy Law, 2005) These electricity prices are much higher than normal fossil fuel prices and will exempt manufacturers from competing with fossil fuel power plants. Grid companies will recover expenses for getting renewable electricity connected to the grid and the cost difference between renewable and fossil energy using cross subsidization. (Wang et al, 2009)

A public fund for renewable energy development was established. Whereas previously subsidies were provided on an ad hoc basis, the REL established a public fund which was financed with general tax revenue. Priorities for the fund are support for renewable electricity generation, research on energy sources able to replace fossil fuels and support for the use of renewable energy by the heating and cooling systems of buildings. The fund is used in two forms: as a grant for financing R&D and for subsidizing loan interest of renewable projects.

A number of other economic incentives have been introduced in order to support renewable energy investment. Financial institutions are encouraged to provide preferential loans to eligible projects. Tax benefits will also be provided for eligible projects. However unlike the case with the above mentioned public fund, no administrative guidelines for implementation of the measures have been published. Older tax policies which do not provide sufficient support for renewable electricity projects are still the only set ones. Custom duty exemptions, as described above, are still around. However, limitations have been introduced in order to help local industries develop. The NDRC has introduced requirements for wind farm development in 2005 which set a 70% minimum bar for domestically produced wind equipment used in local projects. (Wang et al, 2009)

Secondly, the law calls for middle and long-term targets for the total volume of renewable energy at the national level to be set. A series of administrative order and guidelines were published as a result with the Eleventh five-Year Plan for Renewable Energy development (March 2008) and the Mid and Long Term Plan for Renewable Energy Development (August 2007) at the front of these policies.

According to theses two plans, the goal set for renewable energy capacity by 2010 was 300 million ton of coal equivalent. Hydroelectric capacity is expected to account for 80% of total renewable capacity in 2010 as well as in 2020. The goal set for non hydro renewable generation was to account for 1% of all grid connected electricity generation by 2010 and 3% by 2020. By 2020 large electricity investors with capacity over 5000 MW are expected to receive 8% of their total capacity from non hydro renewable sources. Solar electricity was expected to grow from 70 MW installed capacity in 2005 to 300 MW in 2010 and 1800 MW in 2020.

As shown in figure 2.4 PV installations have grown significantly since 2003 and goals have already been reached in 2009. 2010 has seen a dramatic rise in PV installation with 500 MW installed capacity, following 160 in 2009 and 40 in 2008. The last three years have shown a huge percentage rise of installed capacity with 100% in 2008, 400% in 2009 and over 300% in 2010. Following recent success in July 2009 the Chinese energy stimulus plan revised the 2020 targets for installed solar capacity to 20 GW. (China Daily, 2009) On March 23rd, 2011 following the Fukushima disaster, Li JunFeng – head of the NRDC, further increased PV installation goal to 10 GW in 2015 and 50 GW in 2020. (Sun Wind and Energy, 2011)

Chart 2.1 PV Installations in China Since 1990 (MW)

Year	1990	1995	2000	2002	2004	2006	2007	2008	2009	2010
Annual installation	0.5	1.55	3	18.5	10	10	20	40	160	500
Cumulative installation	1.78	6.63	19	42	62	80	100	140	300	800

Source: IEA, 2010[2]. PVPS Annual Report: Implementing Agreement on Photovoltaic Power Systems. Pg. 51. http://www.iea-pvps.org/fileadmin/dam/public/report/annual/ar_2010.pdf retrieved on May 8, 2011

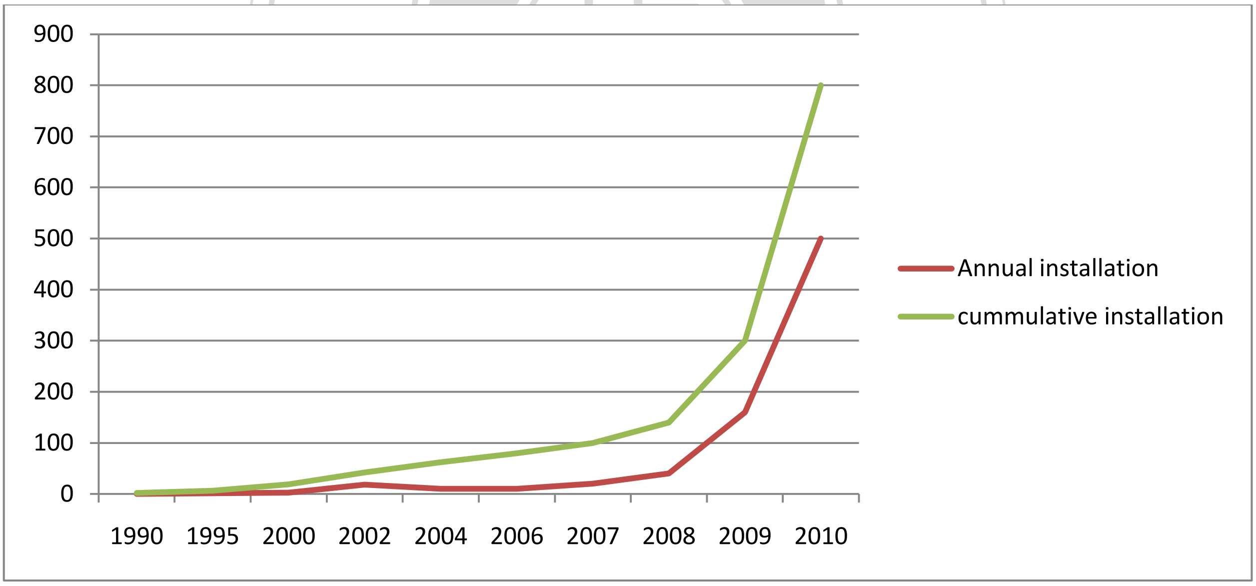


Figure 2.4 PV Installations in China Since 1990 (MW)

Source: IEA, 2010[2]. PVPS Annual Report: Implementing Agreement on Photovoltaic Power Systems. Pg. 51. http://www.iea-pvps.org/fileadmin/dam/public/report/annual/ar_2010.pdf retrieved on May 8, 2011

2.5. PV Promotion Policy

As shown in figure 2.4, PV installed capacity has made rapid progress since the implementation of the REL. As shown in table 2.2 China has given the most attention to rural electrification which accounted for almost half of its generated capacity. Apart from rural development being a national priority, other reasons for the focus on this sector were high PV cell prices and low power tariffs. Various problems regarding renewable energy development emerged during that time. Among these problems were excessive investment, blind construction, insufficient transmission/distribution capacities and the absence of a Feed In Tariff (FID) system. FIT has been introduced in the wind and biomass sectors with a fixed wind power FIT for four different territories being introduced in July, 2009. (Kan, 2010)

Table 2.2 Market Share of PV Power Generation

Market	Accumulative Installation Capacity (MWp)			Accumulated Market Percentage		
Year	2006	2007	2008	2006	2007	2008
Rural Electrification	33	42	48	41.3	42	34.3
communication & Industrial applications	27	30	35	33.8	30	25
PV Products	16	22	30	20	22	21.4
Urban Grid PV	3.8	5.6	26.1	4.8	5.6	18.6
Large scale PV	0.2	0.4	0.9	0.3	0.4	0.6
Total	80	100	140	100	100	100

Source: CTCREP, 2009. The Research and Proposals on Incentive Policy and Measurements of Chinese PV Market Development and the Acceleration. Pg. 96. Consulting and Training Center for Renewable Energy Power, IEE, CAS

The focus on rural electrification came mostly in expense of investment in large scale PV which accounted for less than one percent of the total capacity in 2008. In all leading European countries,which do not have a large rural population, large scale PV accounts for more than 90% of the total market. Despite doubling its installed capacity in just three years since the REL was put into force, China's PV market lacked Diversity in regard to the variety of products it offered, costs reducing plans and local leadership skills.

In order to further promote its domestic market two PV related programs have been initiated in 2009 by the ministry of finance and ministry of construction. In early 2009 the Building Integrated Photovoltaic (BIPV) program was launched with a goal of stimulating urban on grid projects. The program offers RMB 20/watt for construction materials and component based BIPV projects and RMB 15/watt for rooftop and wall based projects. By July 2009 111 projects nationwide have been approved with a combined capacity of 91 MW and a total allocated subsidies of RMB 1.2 billion. The subsidy is provided for large scale (greater than 50) KW) PV panels. (Lin, 2010) In July 2010 the world's largest BIPV system was launched in Shanghai with a 6.7 MW on grid capacity. The project, which was run by the China Energy Conservation and Environmental Protection Group, was partially subsidized by the BIPV program. (Greendiary, July 20th, 2010)

A more ambitious incentive program is the Golden Sun program launched in late 2009 until 2011 aiming at 300 KW or larger PV systems in both off grid rural projects as well as grid connected rooftops, BIPV and on grid large scale systems. The government plans to install more than 500 MW of subsidized projects by the end of the program at an estimated cost of RMB 3 billion. A 20 MW cap has been set for each province in order to assure even distribution. For on grid projects this program offers to subsidize 50% of the investment which includes power transmission and distribution systems that connect to grid networks. Off grid projects will receive subsidization of 70% with a one year completion time. (PVGroup) Together these two programs account for the huge leap in annual installed capacity which was 160 MW in 2009 and an incomprehensible 500 MW in 2010.

Although these two subsidy programs are indeed a concrete form of direct policy the Chinese PV market remains immature and full of challenges. With the current 2010 system cost the national subsidy offered by the program is not enough to ensure a reasonable return on investment. In 2006 an on grid system cost was estimated at RMB 50,000 per KW. This includes feasibility studies and project design, parts, transportation, installation, testing taxes and other fees. The smallest on grid project eligible for government subsidies is 300 KW which is a total of RMB 15 million. The estimated PV electricity price for these scale of projects in 2006 ranged at 3.7-5.5 (Yuan/KW) with the national average electricity tariff being 0.31 (Yuan/KW). (CREIA, 2007)

With these high costs the national subsidy programs do not ensure a reasonable profit on PV projects for developers thus forcing them to rely on additional subsidies from regional and local governments. Currently, the only province which has announced a detailed subsidy scheme is Jiangsu, the manufacturing hub of China's PV industry. Its program is expected to support solar power manufacturers that are already established in Jiangsu and serve as a boost to the development of the entire market, with 400 MW of installed capacity expected by 2011. (SCTBR, 2009)

2.6. Feed in Tariff

More provinces have started working on direct subsidy plans that will reflect the local government's needs and capabilities. However, a series of routines in the form of centralized framework of standards and regulations are still missing. As a result local governments who lack endogenous selection factors (industry and other solar related institutions) tend to avoid Selecting PV as a future strategic investment. Lock-In is strongly felt in this situation as it takes the form of the gap between PV electricity and fossil generated tariffs, as shown above.

China is not expected however to complete its green transition on its own. Countries in Europe have been promoting alternative sources of energy for well over 30 years and best practices can be copied and implemented. The evolutionary framework refers to the adaptation of these best practices as ‘imitation’, a process which fertilizes not only the Selection concept but also Innovation. In terms of Bounded Rationality, the implementation of a Feed in Tariff is the most anticipated stage of the PV transitional development.

An FID offers a fixed price for electricity generation from renewable energy which is guaranteed for a long time. A premium price is paid to electricity generators by the national grid operator the power plant is connected to. The purpose of this mechanism is to encourage the adoption of renewable technology and accelerate its move toward grid parity. FID has been introduced to China’s wind energy sector in 2009 which spurred hope for PV investors, however till date a national policy hadn’t been implemented.

Many obstacles lie in the path for FID implementation. As shown in figure 2.5 there are several price lines for the PV market according to the amount of radiation in different regions of the country. Western provinces such as Qinghai, Tibet and Xinjiang enjoy higher rates of radiation with more annual hours of sunshine which contributes to their system efficiency. Prices have declined considerably in the past 5 years and the average cost of solar power in 2010 was estimated at 2.95 Yuan/KW for residential use and 2.22 Yuan/KW for commercial use. (Rigter and Vidican, 2010)

Price decline is associated with system efficiency and reduction in manufacturing costs, which is directly linked to innovation and technological advancements. According to several reports, China is expected to reach a price gap between PV and conventional energy that is similar to the one in developed countries by 2020. (Rigter and Vidican, 2010, CREIA, 2007) All of this assums though that its market will keep up with world PV manufacturing standards.

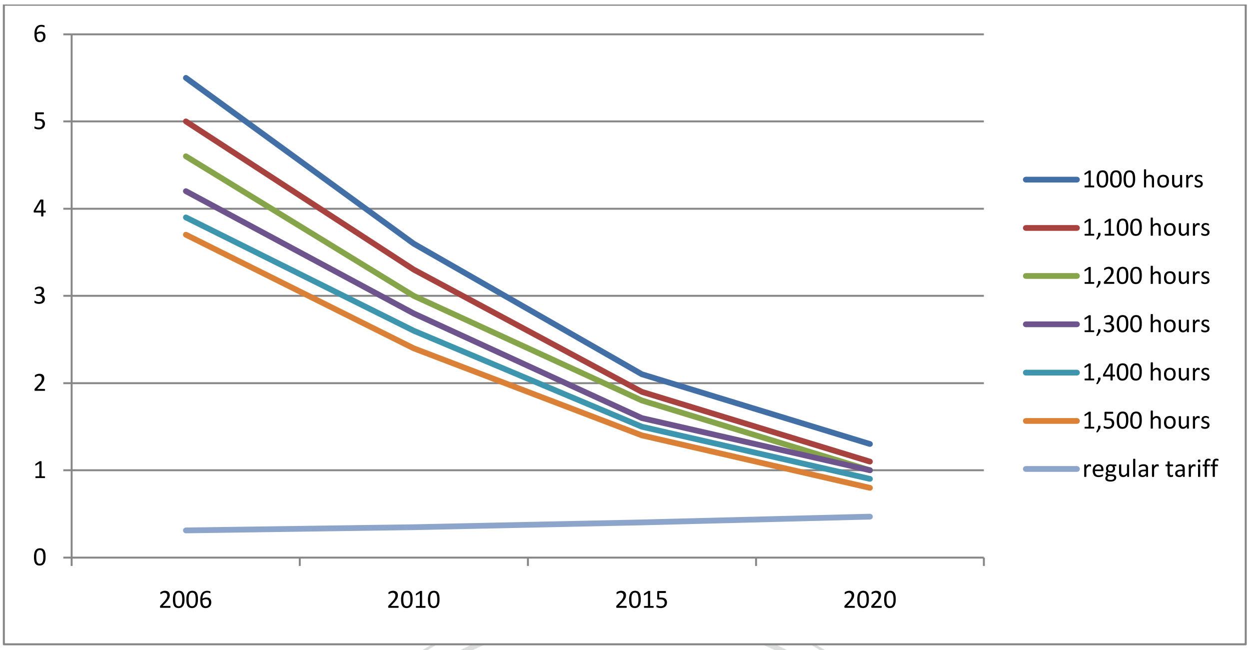


Figure 2.5 Grid Connected PV and Conventional Electricity Estimated Cost 2006-2020 (Yuan/KW)

Source: CREIA, 2007. China Solar PV Report 2007. Pg. 35. China Renewable Energy Industry Association, Greenpeace, European PV Industry Association, WWF

Another element affecting grid parity is the regular electricity tariff. China's electricity prices are heavily subsidized by the state and are considered to be very low by international standards. Prices increase rate is estimated at annual 3%. (CREIA, 2007) Should the government decide to increase rates by annually 6%, 80% of all commercial and residential electricity generation could potentially become eligible to be replaced with small scale PV by 2020. (Rigter and Vidican) This is however not likely as such a decision is expected to have an adverse effect on the broader economy. With no electricity price evolution expected in the near future and fossil fuel generated electricity price likely to remain at its current rate, grid parity will only start to be achieved at 2030.

Another method for quantifying the price gap between PV and other technologies is the Levelised Cost of Electricity (LCOE). According to the EPIA, Solar PV LCOE can reach between 15.3 and 16.5 €cts/kWh. This estimate is low enough to allow PV to compete with diesel fuelled peak power prices which is higher than 16 €cts/kWh but still not close to gas fired peak power cost which is around 10 €cts/kWh. Currently PV is assumed to be able to free some hydro capacity during peak hours but is currently not used as a peak hour energy source. According to estimations, PV has the potential of reaching 5-12 €cts/kWh in China which will enable it to become more competitive than gas or oil fuelled peak power plants. (EPIA, 2010)

An experimental project for a 10 MW PV station in Dunhuang, Gansu province is expected to create a breakthrough concerning policy implementation. A tender in March 2009 have resulted with a joint venture between state run China Guangdong Nuclear Power Holding Corporation, Belgium Enfinity and a unit of private owned LDK (China) presenting the lowest bid. This project is expected to become the base for setting future feed in tariffs for PV in the future. (Kan, 2010)

A FID profits trading mechanism has also been introduced to assure maximum utilization of the incentive packages. Inspired by global emission trading schemes this mechanism allows the trading of surcharges between provinces. Collected renewable energy surcharges are considered as revenue which belongs to the power transmission companies. However some provinces exceed the extent under which surcharges cover their excessive cost of renewable energy purchase. This purchasing cost, which cannot be covered can be sold in the form of credit to other provinces which have unused surcharge income. (Kan, 2010)

The REL has established a renewable energy development fund which provides electric power transmission companies with subsidies for purchasing renewable electricity. This way companies that are in the fund raising stage can more easily apply for funds. The main advantage as mentioned above is that this mechanism enhances the purchase of all renewable energy based electricity. This is an encouraging step which shows that the policy environment promoting PV electricity Selection is improving, through the usage of imitation.

The government however has a good reason for being hesitant in applying FID. As Rigter and Vidican (2010) have shown, technology advancements are causing cost reductions each year. A FID initiated at the end of 2011 is expected to be 29% cheaper than a similar program initiated in 2010. A few years delay might further halt market development but makes financial sense today. When issued, the program will need to set different tariffs to each region in accordance with their radiation utilization potential and the construction costs. The program will also need to include a digression rate for the FIT price in order to match future technological developments.

Currently, developers have to haggle over government fiscal support on the one hand and unenthusiastic grid operators on the other. Although the REL states that grid operators are required to purchase all renewable energy offered the case is not always such. As grid companies are reluctant to absorb the high cost of PV, completed projects find it difficult acquiring grid connection permits. With the state forbidding grid companies from raising electricity prices the prevailing Lock-In it expected to last.

Diversity is growing in China’s domestic PV market as the rural off grid sector’s portion has decreased since the new incentive programs have been set in 2009. Expected projects until 2012 show a 54.6% share of the total 2009-2012 accumulated PV market. (CTCREP, 2009) China has shown in the last couple of years market patterns that are beginning to resemble models found in developed countries.

The case is not so when it comes to developers involved in the market. The Dunhuang project has offered 1.09 Yuan/KW as its Power Purchase Agreement (PPA) (kan, 2010) which is significantly lower than the optimal 3.89 Yuan/KW introduced by some researchers (Rigter and Vidican, 2010). Most companies from the private sector and from overseas either stayed away from the new bids or were unsuccessful as they were not prepared to go under or near the 1 Yuan line in order to penetrate the market.

This leaves a space which is filled by state owned companies. Such companies are more daring and loose in terms of project financing and biding as they have a long security net. The domestic Chinese market is still very small and is still waiting for a string public drive to shake it, however at the moment there is a clear bias towards China's big domestic manufacturers with a focus on the state owned ones. In order to further promote local industry a cap of 25% of project financing sourced from foreign capital has been set which guarantees continuity in market hegemony in the near future.

A second round of concession tenders of PV projects is underway since mid 2010 following the 2009 Dunhuang concession. These projects spread over six provinces with a total installed capacity of 260 MW. As tendering price is expected to be even lower than the first round, previous gained experience will play an important guiding factor for the future of the market. (Ma, 2011)

2.7. Connection to the Grid

Another reason for the central government to keep the PV energy market under low fire these coming years is that its domestic grid isn't yet ready to accommodate the fast growing number of renewable resources. A quick look at the wind sector shows that between 30% and 50% of installed wind power capacity is not being extracted into the grid and is simply wasted. Enterprises are still reluctant to build grids and connect wind power plants to the main grid network, even though they are required to do so by the REL. Some renewable power plants have had no choice but build grid connections by themselves or share the connection costs which is a violation that is not being dealt with. (Wang et al, 2009)

The inconsistency of wind and solar power makes it technologically difficult to capitalize on the full potential of renewable power in the current grid system. Conventional grid systems can accommodate up to 30% of intermittent energy. In this part of the evolutionary transition wind and PV energy only play a complementary role to conventional energy resources, and is expected to account for only 3% of china's total energy mix by 2020.

Expectations are that when PV or wind power plants work at high output coal fired power plants will reduce their output which will prevent overloading the grid and reduce pollution. Smart grid can better manage the balance between demand and supply and is expected to play a vital role in the efficiency of future systems. Also, large scale wind and PV projects like the 2 GW project planned in Ordos city requires significant adjustments to the grid which include smart grid technology. This aspect of the system relates to the concept of Co-evolution. As China further develops its PV market it needs to develop and invest in smart grid technology as well.

Smart grid is expected to become a big player in china's domestic market as a part of the 12th five year plan (2011-2015). The state grid, china's largest power distributer is planning to increase its investment in smart grid upgrades and installments to RMB 500 billion (USD 76 billion) with the 5 year plan whereas in the 11th five year plan it invested only RMB 20 billion. (China daily, 2011)

Despite considerable efforts China's success in promoting the PV electricity sector has been partial. Installments rate has gone significantly up due to direct government subsidies and incentive plans. These measures are not a complete solution however as they do not remove Selection problems from effecting the market. The low cost of conventional energy production is expected to prevent grid parity from being reached in the near future. Since the introduction of a state FID scheme is not likely in the coming few years, the market is going to continue relying on direct incentives rather than on a more general and balanced mechanism. It does seem that if FID will be introduced down the road China will be able to gradually start shifting away from the low tariff of conventional power production which is the major Lock In it is trying to break away from.

The main finding from the market analysis presented is that the strength of the recent market development is mostly due to efforts in terms of Selection. The heavy reliance on subsidies and funds for PV installations promotion is a great promotional tool that helps raise awareness to the sector in the short term. This approach is not sustainable in the long term as a direct subsidy lowers developers' responsibility to efficient deployment spending. Current deployments are estimated to be more expensive than deployments in China are estimated to be. In short, a subsidy program such as the golden Sun program or the BIPV program does not set criteria for project efficiency, rather only for feasibility of project return of investment. China needs to introduce a reliable FID mechanism to allow a more efficient development of the market and guarantee that only healthy feasible projects will be carried through.

The excess reliance on Selection patterns affects the Diversity of the market with state owned enterprises dominating the bidding auctions. Considerable efforts have been made as well in order to create a balanced mechanism that controls state subsidies. This has been done with partial success as companies still report unwillingness to enter the market due to lack of certainty concerning permits approval and building regulations.

More regulations still need to be written concerning connection to grid in terms of financing and responsibilities. Grid connection is currently a bottle neck which will need to be dealt with in order for the market to grow. This problem is the result of Bounded Rationality in the sense that some parts of the system cannot position themselves in order to encourage a balanced Selection pattern. It seems as though the central government hasn't done enough concerning that aspect yet.

Chapter 3 - China's Photovoltaic Industry

The previous chapter discussed the relations among the central government and PV developers in the Chinese market. As shown, there is still much progress to be made in terms of regulations and incentives in order for China to continue its journey to grid parity. Government regulations directly affect all 6 components of the evolutionary model. In china, these regulations take an even greater role due to the still very centralized economy.

This chapter will focus on the local PV industry, being an important necessary driver to the local market. As mentioned above, unlike the huge gap between China's PV market potential and its current situation, the local PV industry has developed much faster. In 2009 total production was estimated at 4011 MW of solar modules capacity. Annual production in 2010 is estimated to have nearly doubled, from 7000 to 8000 MW, which places China as the supplier of over half of the world's total modules.

Table 3.1 Annual Cell Production

Year	2007	2008	2009	2010 (expected)
PV production (MW)	1,088	2,600	4,011	8,000
annual growth	172.0%	139.0%	54.3%	99.5%

Source: IEA, 2010[2]. PVPS Annual Report 2010. Pg. 51. http://www.iea-pvps.org/fileadmin/dam/public/report/annual/ar_2010.pdf retrieved on May 5, 2011.

Because of the undeveloped domestic market China's PV industry has been traditionally targeting foreign markets as its growth engine. As of 2010 the total global installed capacity has been almost 40 GW with the EU constituting around 75% (almost 30GW). Germany is the world market leader with over 7 GW of installed capacity in 2010 followed by Japan with over 3.5 GW and Italy with over 2.3 GW. (EPIA, 2011[2])

In the beginning of 2011 80-85% of global PV cells produced were crystalline silicon (c-Si) technology cells. China's PV industry has given an even greater production focus on these cells with over 90% of its industry capacity dedicated to c-Si manufacturing. This chapter will focus on the c-Si industry and asses the role it plays in the energy transition, being the single most important driver to the Chinese PV market today. With government policy playing a constructive role in the PV industry as well, elements as Bounded Rationality and Selection need to be discussed. As will be shown, diversity is the most important element which will determine the extent in which the industry could support a growing domestic PV market. Chapter 4 will present other technologies that complement the Chinese PV industry growth.

C-Si is the most mature and common PV technology. Crystalline silicon cells can turn 14-22% of sunlight that reaches them into electricity. The two main types of c-Si cells are mono crystalline and polycrystalline, the first holding higher efficiency rates than the latter. There are five steps in the c-Si manufacturing process as shown in figure 3.1. Many module manufacturers in China are trying to upstream their production lines in order to vertically integrate the different steps under one umbrella.

A PV system does not consist of only modules of course. All components aside from the modules are regarded as Balance Of System and include structures, enclosures, wiring, switch gear, fuses, ground fault detectors, charge controllers, batteries, and inverters. These components do not make a big part of the domestic industry and key parts of it such as inverters, batteries and charge controllers are imported.

Figure 3.1 Crystalline Silicon Manufacturing Process

3.1. Production of Solar Grade Silicon

Silicon is the second most abundant element on the earth's crust after oxygen. However it is the first step of the c-Si production line that has been the bottle neck of the industry for the past 6 years. Solar grade silicon or polysilicon is the key raw material in the manufacturing line, therefore plays an important role in determining the industry success. The market for polysilicon is shared between electronics and solar. In 2000 only 10% of the polysilicon market was used to produce solar cells, and there were only two main producers in China: Emei Semiconductors and Luoyang High-Tech. (with combined 80 tones of production)

3.1.1. Early Development

It wasn't until 2005 that local manufacturers started increasing their capacity as both companies expanded their production scale to a combined 400 tones which led output to rise the following year to 300 tons. Spurred by the growth in the European market and the strong government subsidies at the time, more companies entered the market with installed capacity reaching over 4000 tons and output passing 1,100. (Zhao et al, 2008)

Domestic supply has never managed to keep up with the industry's growing demand. As shown in table 3.2, with an annual demand growth of over 100% in average the solar module process heavily relies on imports to sustain its production line. In 2006 silicon material prices hiked and boosted investment in polysilicon production. Until 2008 over 90% of global production was contributed by 7 leading manufacturers, with Korean OCI being the only new major player in the market since.

Table 3.2 Polysilicon Production and Demand 2006-2010

Year	2006	2007	2008	2009	2010
Production (Ton)	300	1,100	4,729	20,357	42,890
Demand (Ton)	4,000	10,000	25,000	40,000	80,000
Shortage (Ton)	3,700	8,900	20,271	19,643	26,310
Share of Import (%)	92.5%	89.0%	81.1%	49.1%	46.4%

Source: IEA, 2010[2]. PVPS Annual Report 2010. Pg. 48. http://www.iea-pvps.org/fileadmin/dam/public/report/annual/ar_2010.pdf retrieved on May 5, 2011.

As a result of tight polysilicon supply prices have been constantly going up since 2003. Until that year solar grade silicon price was around 25 USD per kilogram in China. However with the PV sector growing in Europe and Japan, and the slow construction pace for new factories (2 years), production hasn't managed to answer global demand. Prices have started to soar, doubling by 2005 and reaching up to an unprecedented 500 USD/kg in 2008. (Mayers and Yuan, 2007)

The international financial crisis in 2008 has caused the market price of silicon to drop dramatically and reach a bottom 40 USD/kg in April, 2010. With the economic recovery and the drop in upstream prices global PV installations have been booming which increased once again demand for polysilicon. Prices have also started to gradually increase with spot prices ranging from 60 to 80 USD/kg in October 2010. The polysilicon spot price in China has exceeded 100 USD/kg in December 2010. (Research and Markets, 2011)

3.1.2. Between Shortage and Oversupply

Due to the lack of domestic manufacturing despite the government goals presented in the Medium and Long Term Development plan, the central government began supporting the promotion of domestic polysilicon material technology development. Local governments came up with special incentives in order to secure the industry's vital upstream sector, and cash rich companies have been attracted by the huge profits potential. Dozens of small and medium size polysilicon companies have emerged in an attempt to capitalize on the industry's demand gap. (Kan, 2010)

A unique example is the municipal government of Sichuan which has invested in 2008 RMB 6.5 billion in Tongwei group which is expected to construct a 9000 tons polysilicon manufacturing plant by 2011. The company's annual sales income is expected to reach RMB 20 billion by 2012. The third step of the project will be to integrate the polysilicon plant with a downstream facility which will produce complete modules, thus making Tongwei a world leader in the PV industry.

Not all projects have boasted such a large scale of production. Around four out of every five new companies established since 2008 are small companies with annual capacity of only a few hundreds of tons. (CNCiC Consulting, 2011) While the central government has declared the PV industry to be of national priority in the REL, the large number of new market entrants is currently threatening in overflowing the market. In September 2009, 68,000 tons of polysilicon projects were under construction and another 127,000 tons of capacity for planned projects were approved. (Herron, 2011)

Seemingly with this amount of capacity China's polysilicon industry would be on its way to grab a big share of the global market and answer its domestic needs. The major problem with the current capacity expansion model is that experience has shown that economies of scale are important for an enterprise to be able to compete in the global market. In order to reach the current spot rate of 60-80 USD/kg a factory needs to have a minimum capacity of 1000 tons. Many of the Chinese companies are expected to either encounter problems in the market penetration stage or have to sell in a loss.

Either way, the government is concerned about the threat small producers might pose to banks. With the global players declaring of capacity expansion in 2012 (Hemlock, OCI and Wacker are working on a 15, 20 and 10 thousand tons of expansion capacity) the global market is expected to become flooded and prices will drop or maintain their current spot price. Smaller players will be the first to suffer a downturn and the scenario of a long list of non paying loans is looming in front of decision makers.

In an attempt to restore order in the market and promote a more sustainable industry growth the NDRC have introduced regulations that will curb the runaway growth of noncompetitive low quality companies. According to the new policy, new factories will need to produce more than 3,000 tons annually as a preliminary criterion. Moreover, in order to facilitate a healthier financial structure polysilicon plants will be required to have at least 30% percent of its capital coming from equity. Facilities will have to be built in an area of no more than 6 hectares for 1,000 annual tons and reduce their electricity consumption rates. (Goossens, 2011)

3.1.3. Industry Leaders

The extent to which companies that do not comply with these regulations will be shut down is yet to be revealed. The direct benefiter of this policy will of course be the large state champions that have a well known reputation and already comply with the new regulations. GCL is china's largest polysilicon producer with annual production of 21 thousand tons and ambitious expansion plans for 65 thousand tons by the end of 2011. (Herron, 2011) Along with LDK, ReneSola Ltd. and Yingli Green this corporations have access to huge lines of credit from the China Development Bank and are a part of the few companies in China that have the resource potential to compete in the global market.

3.1.4. Technological barriers

Apart from scale, technology is also a significant barrier for a sustainable growth of the Polysilicon sector. Products along the PV supply chain are very standardized. Successful entry to the industry therefore requires access to state of the art production technology which in its turn requires a competitive international production equipment market in order to have price reduction. This is of course not the case in China, as the market is dominated by a small number of firms. Only the 4 big polysilicon producers in china have invested in the high quality expensive production machinery which while making them potential future global leaders intensifies the gap between them and small competitors.

The purification process of turning metallurgical grade silicon into electronically grade silicon is mostly based of the Siemens process. All except for one factory in China produce using this process which has been publicly available for years. Although well known, this process is challenging as in order to purify silicon within reasonable costs all chemical reactions parameters need to be tightly controlled. Global major producers have developed advanced know how which they keep as a secret. In order to create a competitive silicon segment in the Chinese PV industry domestic R&D efforts need to be placed.

China's innovation in the silicon industry has been remarkably high, taking over 35% of the total world patents. These R&D efforts are mostly funded by public authorities as within these patents over 60% are listed as public. (Tour, 2010) The Chinese weight in patent applications in the silicon purification field is yet not showing technological leadership as these patents are mostly not appreciated abroad. However, they do show a governmental effort to break this technological barrier which at the time forces market development to rely on foreign supply.

Currently China's domestic solar grade silicon sector is lacking in technological innovation and production optimization. This is a result of lack in efficient know how and Innovation. With the main producers all relying on the Siemens mature technology the industry lacks in Diversity which in its turn lowers the potential for cross fertilization and cooperation to take place. Obviously some effort has been made with governmental investment forwarded to public research institutions and universities which pay a great deal of attention on patents. With economies of scale picking up and new industry standards in place the sector is expected to become more productive in coming years. So far industry players and facilitators have given more attention to routines and imitation and the number of venture capital funds is low in this sector.

3.2. Ingots and Wafers

These two sectors of the manufacturing chain are usually integrated as a part of the same production line. An ingot is a cylinder or a brick of silicon which is grown from pure silicon. Two conversion processes are possible in this stage. A single crystal (monosilicon) is a more efficient PV cell, up to 18% efficiency in field testing. Its manufacturing process has large power consumptions therefore more expensive to produce. Multiple smaller silicon crystals (polysilicon) are less efficient ranging from 12 to 15%. Once the ingots are grown, they are sliced into thin layer called wafers and are polished.

3.2.1. Market Share and Global Trends

Unlike the silicon production sector, there are fewer barriers of entry to the ingot and wafer process. Standard production facilities can be bought and the technology is out there to use. Like the silicon sector, a significant capital outlay is required although factory construction isn't as time consuming. This sector is traditionally less competitive than the silicon sector as its global top 5 companies used to share 93% of the wafer market until 2008. About 50% of the market is controlled by companies which are already related to the polysilicon segment. For example, Japanese SUMCO which holds

31.5 of the global market is the merged wafer operation of Sumitomo and Mitsubishi which have both upstream and downstream production lines.

A survey conducted by Green Rhino Energy (GRE) in 2009 has listed 17 Chinese companies which played a dominant factor in the ingot/wafer industry, apart from the big 5. Out of these companies only 2 were listed as vertically integrated into polysilicon downstream production lines. GCL, being China's leading domestic Polysilicon manufacturer, is integrated only into mid-stream production, whereas Jiangxi Trinity, being one of China's top 3 PV manufacturers, covers the chain from polysilicon to modules. (Green Rhino Energy, 2009)

On the other hand, upstream integration is a much more common practice. The GRE report has estimated that 40% of global cell producers are already integrated into wafer cutting. 11 of the companies mentioned in the report have been listed as having a combined downstream manufacturing chain. The vertical integration is mainly towards upstream with cell/module manufacturers expanding their production line into wafers. Leading Poly/wafer manufacturers are more cautious towards entering the overcrowded mid stream sell segment. (Colville, 2011)

3.2.2. Industry Leaders

As a strategic decision, leading wafer manufacturers such as GCL and LDK are busy positioning themselves as suppliers to designated cell manufacturers. In recent years these two firms have shown impressive growth in the wafer segment, which has undermined the traditional domestic and global status. In 2005 almost no Chinese firm was involved in wafer production. Following the growth of the PV market in Europe in 2003 and the awakening of domestic production, LDK was founded in order to capitalize on the gap in the production chain (thus cutting wafer imports from foreign manufacturers, particularly from Japan).

LDK expanded its wafer production capacity from 215 MW in 2006 to 3 GW in 2010 with expansion plans to reach 4 GW by 2011. During its first years, the company built production facilities in china's PV production hubs in Jiangxi province and near Shenzhen in order to supply the big cell producers. In 2008 the company expanded upstream to open its own polysilicon manufacturing line. This strategic move gives LDK a stable supply line for their wafer operations as well as increasing profits. Wafer processing remains however LDK's core competency. The firm has given special focus on innovation in downstream and upstream sectors in order to create future expansion opportunities. The company has started expanding into the module production sector as of 2009 with 500 MW and the cell manufacturing sector in 2010 with a capacity of 580 MW. (Osborne, 2011)

Currently, the ingot and wafer sectors still rely heavily on polysilicon imports. The lack of feedstock and the price rise which followed have caused the sector to develop slower than the downstream sectors. Until 2007 factories have been producing at only 25% of their capacity despite an annual average capacity rate of over 70% increase since 2004. (Zhao et al, 2011) A possible explanation is that Ingot and wafer technologies are relatively mature and present a lower technical barrier than the polysilicon sector. Moreover, in 2007 the ingot and wafer industries constituted more than 40% of the PV industry profits which along with the polysilicon sector constituted a bulk portion of the potential profits.

GCL is another industry success story, being a firm that has successfully entered the ingot/wafer sector using a unique business model. Having its core competency in the polysilicon sector, GCL has emerged in the last two years as one of the largest wafer suppliers through a series of joint ventures with cell and module manufacturers. As a part of its business model GCL has taken upon itself to developing plants that will exclusively supply wafers to its joint venture partner, and have these plants custom made to its specific needs. In may 2011 GCL announce a joint venture with china based Canadian Solar to build a 600 MW capacity wafer plant in Suzhou which will be dedicated to Canadian Solar's requirements, and might be expanded to 1.2 GW in the future. (Solarbuzz, 2011) A month later the firm announced a joint venture with Goldpoly to build a 300 MW wafer plant in Quanzhou which will both serve for Goldplay's requirements and could serve as a possible spring board to the Taiwanese market due to geographical proximity. (PVtech, 2011)

3.2.3. A Non Diverse Industry Segment

A unique aspect of China's domestic wafer industry is that unlike the global industry trend it consists of mostly mono-crystalline production. In the rest of the world the ratio of mono-crystalline to polycrystalline production is around 1:2, however almost all local production in China was concentrated on one sector of the industry. This can be explained due to the fact that the technology for producing mono crystalline material is the most mature one in the industry which allows equipment to be manufactured domestically.

Companies with a short term vision choose to stick to cheaper modes of production therefore affecting the industry Diversity. (CREIA, 2007) With the rapid expansion of LDK and GCL new technology has been assimilated and the production ratio has shifted a bit closer to international standards, however China still produces mostly mono-crystalline ingots and wafers. China also still depends on imports for wafer production equipment.

Table 3.3 PV Industry Segments Economic Features in 2007

Segment	Investment Cost (million USD)	Technological Barriers	Percentage of profit
Polysilicon	140	high	41%
Ingot and Wafers	95	medium/high	41%
Cells	125	medium/low	11%
Module	25	low	7%

Source: Tour Arnaud de la, Glachant Matthieu, Meniere Yann, 2010. Innovation and International Technology Transfer: the Case of the China Photovoltaic Industry Pg. 8. http://econpapers.repec.org/paper/haljournl/hal-00498578.htm retrieved on April 2, 2011

This is an example of the importance of joint ventures and foreign direct investments to the Diversity and Innovation in China's domestic PV industry. Although China has attracted in 2009 about one third of the global Foreign Direct Investment flows in the PV industry it has not been a decisive factor in the emergence of the industry. In 2009 few PV manufacturers in China had financial links to foreign companies and most of the FDI based firms are in fact late entrants to a market dominated by domestic firms.

In 2009 China had around 70 firms manufacturing in the ingot sector and 178 in the wafer sector. This constitutes a significant jump from 2007 which listed only 38 silicon wafer manufacturers. (CREIA, 2007) These numbers are still significantly lower than the number of firms performing in the cell and module sector. The ingot/wafer sector is currently the sector with the most domestic equipment suppliers and is the fastest growing in the PV production chain. It can be assumed that in the coming years domestic investors will continue expanding this sector, thus further lowering costs, strengthening midstream supply and stabilizing domestic production.

In the time following the global financial crisis traditional wafer spot prices were around 5 USD. However due to growing supply manufacturers have been quoted below the 5 USD rate, with reported inventory pressure. (icFull, 2011) It seems as if the sector is well positioned to support a further growth of the Chinese market in 2012, with all eyes laying on the central government's future initiatives.

3.3. Cell and Module Industry

These two sectors are the most mature in the PV production chain. Cell production is the assembling of two different doped wafers together so that they form what is called the p-n junction which is responsible for the photovoltaic effect. After the cell is produced it is encapsulated in glass sheets to form a module which will be cooked in a laminating machine. The technology barriers to cell and module manufacturing are relatively low and in the case of module production also require smaller amounts of investment.

3.3.1. Sector Growth

China is the world's leading cell and module manufacturer showing impressive growth rates in the last 5 years. Unlike silicon processing, cell and especially module assembling is labor intensive which gives Chinese firms a competitive advantage. Labor is estimated at only 1-2% of the total cost of China's module production segment in contrast to 5-10% in developed countries. China capitalizes on its cheap labor into becoming the manufacturing hub of solar cells and modules. Engineers just graduated from university can be found in China for a salary of only about 2,640 USD a year. (NYT, 2010) This therefore follows a similar pattern to the one which led it to become the manufacturing hub for other industries.

The first generation of Chinese PV manufacturers came from the solar cells sector. These companies, established in the 80's were state owned and depended entirely on imports of key equipment and whole production lines at times. As the country failed to present incentives for engagement in technology research and innovation, there were many bottlenecks in the lines and production was at around 20% of capacity. (Marigo, 2005)

The second generation of companies which started in the early 2000s was driven by market demand and was not dependent upon the central government priorities. Having followed the strong drive of the world PV market the sector showed rapid growth numbers. According to Energy Focus in 2011 there are more than 600 Chinese companies which are involved in the production of complete solar panels. It was estimated that in 2008 alone around 60 cell production companies existed and over 330 module encapsulating firms. (Ma, 2009) Despite raw material constraints, new companies are continuing to enter the industry, with overcapacity becoming a relevant issue in terms of 2012 production rates.

Apart from the polysilicon production stage, each segment of the supply chain has a significant number of equipment suppliers. The downstream segments have a significantly higher number of suppliers as shown in table 3.4. Almost all solar cells manufacturing equipment can be found domestically. However due to quality issues some of the machinery is still imported at a high price. For example, only half of the wafer cleaning machines is domestically produced.

The case is different for module encapsulating equipment which proposes the lowest technological barrier. Hundreds of machine manufacturers offer different levels of technological solutions which encourages fiercer competition and more options for companies involved in the segment.

Table 3.4 Manufacturing Equipment Providers in the PV Industry

	Ingot	Wafer	Cell	Module
All firms	70	178	335	234
Turn-key production lines	1	9	15	26

Source: Tour Arnaud de la, Glachant Matthieu, Meniere Yann, 2010. Innovation and International Technology Transfer: the Case of the China Photovoltaic Industry. Pg. 9. http://econpapers.repec.org/paper/haljournl/hal-00498578.htm retrieved on April 2nd, 2011

Unlike the polysilicon, ingot and wafer segments, a significant number of turn-key companies exist in the cell and module segments that allow production to start with a minimal level of technological knowledge. (Tour et al, 2010) This is another catalyst which led to the fast growth of the industry.

Interaction with international suppliers should not be evaluated on the basis of production costs alone as it has unique benefits. This form of interaction gives manufacturers an opportunity to gain know how and give and receive feed backs regarding ways of improving the manufacturing process. This accelerates the circulation of knowledge across the industry which helps Chinese manufacturers reach higher production standards. Imports of international equipment are a key component of the Diversification of the manufacturing industry and are crucial for Innovation and exchange of ideas.

3.3.2. Industry Leaders

Taking a look at the marketing strategies of Suntech and Yingli, two of China's leading cell and module producers helps us understand the dynamics of the downstream sectors.

Suntech was founded in 2001 in Wuxi city, Jiangsu province under the support of the local government. Its founder, Dr. Shi Zhenrong has studied and worked for over ten years in Australia where he gained practical knowledge on the solar industry. In general Chinese PV companies have benefited greatly from the arrival of highly skilled executives that have received their education and expertise abroad and brought with them capital, professional network and technology. Many of the board members of China's leading PV companies are overseas Chinese that have studied and worked abroad. Chinese firms are developing specific programs to attract overseas educated mid-level management employees. (Tour et al, 2010)

In 2007, more than 98% of Suntech's product output was sold outside China with over 85% of its revenue coming from the European market. Germany was Suntech's largest sales destination accounting over half of its revenue followed by Spain. Being heavily dependent on foreign markets Suntech is suiting its production capabilities to match its market's needs. In 2006 it acquired Japanese PV module maker MSK in order to gain BIPV technology capacity. This acquisition is enabling the firm to further expand into Spain and penetrate new markets in Japan and the US which are considered to be major BIPV markets.

Suntech is also taking active steps in developing its markets as it started to build in 2009 a 30MW PV power plant in Texas in a joint venture with MMA renewable ventures. The company is expected to further develop the US market in coming years and is considered to be the best placed firm to enter the US market in the coming years. These international activities compensate for a very small domestic market. In 2010 China accounted for only 1-2% of Suntech's annual revenue. With the rapid growth of the domestic market in the last three years, the company is expecting percentage to rise to 10% in the coming two years.

In general, Chinese producers are not major innovators. They devote much less revenue to R&D than other western firms, which usually accounts to less than 1% the yearly turnover. Surprisingly the number of patents introduced by Chinese companies in the downstream sectors is considered high (15-16%) which rates China third in number of patents. However, only 1% of Chinese patents are filed abroad, in contrast to 15% for Germany and 26% for Japan. The value of the downstream Chinese patented inventions is considered low.

Suntech is an exception in that aspect as it dedicates a greater portion of its revenue in research and development. In 2009 for example, about 5% of its revenues went to R&D projects. (Technology Review, 2010) It has also established research cooperation relations with several universities. Suntech's Innovation is mostly directed at maintaining its high competitive level in the c-Si silicon solar cells in terms of energy conversion efficiency of mono-silicon cells, which as mentioned above is the most common wafer technology in China's domestic industry.

Yingli is China's third biggest solar cell producer with an estimated 1 GW production in 2010. It is one of the world's biggest vertically integrated firms although its wafer production capacity still lacks behind the domestic sector leaders. Unlike Suntech, Yingli was founded privately by Mr. Miao Lianshen in 1987. In 1998 an investment company controlled by the local government of Gaoxin Districy in Baoding, Hebei province bought a 60% stake of Yingli which enabled the company to found Baoding Yingli new energy resources co.

Yingli mostly focuses on the European and US markets, however in recent years the company has shown interest in penetrating developing Asian markets. In 2008 Yingli signed contracts with a number of market developers in Korea with a total of 7 MW of PV modules for grid connection installations. (PVtech, 2008) In 2011 Yingli started entering the market in Japan with a 10 MW PV module distribution contract signed with YHS, a joint venture mostly involved with IBPV development. (PVtech, 2011)

Perhaps due to its complete domestic vertical production line, Yingli has been selected as the major PV module supplier to the government's Golden Sun project. As mentioned in Chapter 2, this program is heavily subsidized by the ministry of finance which is expected to attribute 70% of subsidies to Yingli, thus turning it into China's leading PV modules supplier. (PVtech, 2010)

2010 was a very successful year for Chinese solar companies as Europe's market demand, driven by generous subsidies as a part of different FIT schemes, has raised capacity utilization to its limits. Most leading Chinese firms such as Suntech, Yingli and LDK are already going through massive expansion programs. Yingli alone has been reported to increase its capacity by 70% in 2011.

These recent expansion plans come however in time where Governments in Europe are scaling down their solar subsidies. 2012 is expected to be much slower than previous years in terms of European market demand with Germany, Spain, Italy and the Czech Republic expected to reduce their FIT. European analysts are claiming that the amount of capacity being added is ahead of what the market can take. (Bloomberg Businessweek, 2011) Chinese manufacturers today have a new priority in diversifying their customer base.

3.3.3. Municipal Drivers Toward Industry Selection

While most major companies have already made significant efforts in penetrating new markets in the US and Asia, the growing local market is retaining a growing strategic importance. The reason is that political pushback against solar subsidies is also driven by claims that foreign manufacturers are the ones benefiting the most from them. France's environment minister has claimed before that environmental policies should create jobs in France and not subsidize the Chinese industry.

China's domestic industry holds a significant advantage concerning the direct support it has been receiving from within. Chinese state-owned banks and municipal governments have been reported to offer unbeatable assistance to Chinese solar panel companies in what has been one of the industry's important competitive advantages. According to a report by the New York Times from January 2011, China's cheap labor is only one aspect of the advantage its domestic industry holds, whereas creating partnerships with local governments plays a greater supportive role. With the help of Municipal governments, firms can borrow up to two thirds of a factory construction cost with an interest rate lower than 5 percent. A similar venture in the United States would require a significantly larger amount of equity as banks are reluctant to provide loans because of the financial crisis. Authorized loans are expected to have double digits interest rates.

As a result of favorable operating conditions companies have been shutting down factories and moving production lines to China. Such is the case with Evergreen, the Unites State's third largest solar panel maker, which has closed its main production factory in the states and has shifted its production to a joint venture with a Chinese company in central China's Wuhan. This has happened despite a total of USD 43 million was offered in assistance by the government of Massachusetts in recent years.

Evergreen is not alone. Other solar panels manufacturers are struggling in the United States such as Solyndra which has recently shut down one of its manufacturing plants and has delayed expansion of another. British BP has also shut down its solar panel manufacturing in Spain in order to expand on a joint venture in China. (Energyboom, 2010)

Apart from generous loans and low interest rates, municipal governments have been supportive in other aspects. For example, Hunan Sunzone Optoelectronics has received 22 acres of valuable urban land close to downtown Changsha at low prices which reduced the company's costs and increased its attractiveness to investors. Moreover, China's famous bureaucracy which is known for having a strict hand against foreign developers is extremely cooperative in the process of project authorization. Sunzone has reported receiving the permits necessary to build its factory in just three months. Another eight months are dedicated to building and equipping the factory after which the factory's capacity is intact and is ready to start production. The construction phase of building a similar factory in the United States will take over a year alone, with the preliminary permit procedure lasting an even longer time than that. (NYT, 2010)

These different measures are a result of the PV industry being categorized by the central government as a crucial expert industry. They are considered to be a standard procedure in all sectors of the industry. The United States government and other European governments have shown discontent over these measures referring to them as creating an illegal industry advantage. According to the World Trade Organization regulations, countries should not provide subsidiaries to exporters as this lowers other countries' industry competitiveness and shakes the free market off balance. For the past decade China has failed to provide a list of its national subsidiaries as is expected from every WTO member, therefore frustrating mostly western governments. In October 2010 the Obama administration pledged to the WTO to investigate Beijing's subsidies to its clean energy industries. (NYT, October 15th, 2010) Governments around the world are looking for ways to reduce their reliance on China's solar industry in what is becoming a threat to its future growth.

3.4. Cost of the Domestic PV Modules

The success of the efforts made in promoting the Chinese PV industry is measured in the short term through pricing. Modules play a significant role in the costs of PV system installations as they account for around half of the overall cost. An efficient module industry is therefore the most crucial aspect in cost reduction towards grid parity.

Table 3.5 Cost and Price of PV Manufacturing Components in China and Overseas (USD/W)

	Poly-crystalline Silicon	Ingot/wafer	Solar cell	PV module
Cost (domestic)	0.63	0.3	0.3	0.3
% of total	41.2%	19.6%	19.6%	19.6%
Cost (overseas)	0.56	0.3	0.5	0.55
% of total	29.3%	15.7%	26.2%	28.8%
Price (domestic)	0.63	1.19	2.02	2.63
Aggregated cost (domestic)	0.35	0.93	1.49	2.32
Value-added (domestic)	0.28	0.26	0.53	0.31
Price (overseas)	0.56	1.21	2.16	2.96
Aggregated cost (overseas)	0.3	0.86	1.71	2.71
Value -added (overseas)	0.26	0.35	0.45	0.25

Source: CTCREP, 2009. The Research and Proposals on Incentive Policy and Measurements of Chinese PV Market Development and the Acceleration. Pg. 78. Consulting and Training Center for Renewable Energy Power, IEE, CAS

China's Consulting & Training Center for Renewable Energy Power has published a comparative set of data of the domestic and international c-Si production line prices as they were recorded in May 2009, more than 6 months into the financial crisis. The data presented in table 3.5 relates to the poly-crystalline spot rate at that time which was USD 90/kg. The total cost of PV domestic modules production in 2009 was USD 1.53/Watt whereas production of international modules was estimated at an average of USD 1.91/W, almost 25 percent higher. Poly-crystalline accounted for 41.2 percent of the domestic production being USD 0.63/W. In the international market this sector has shown better figures being USD 0.56/W and only 29.3 percent of the total production cost. This percentage of total production is to be accounted for the fact that production costs in both the cell and the module sectors were significantly higher than China's domestic production line.

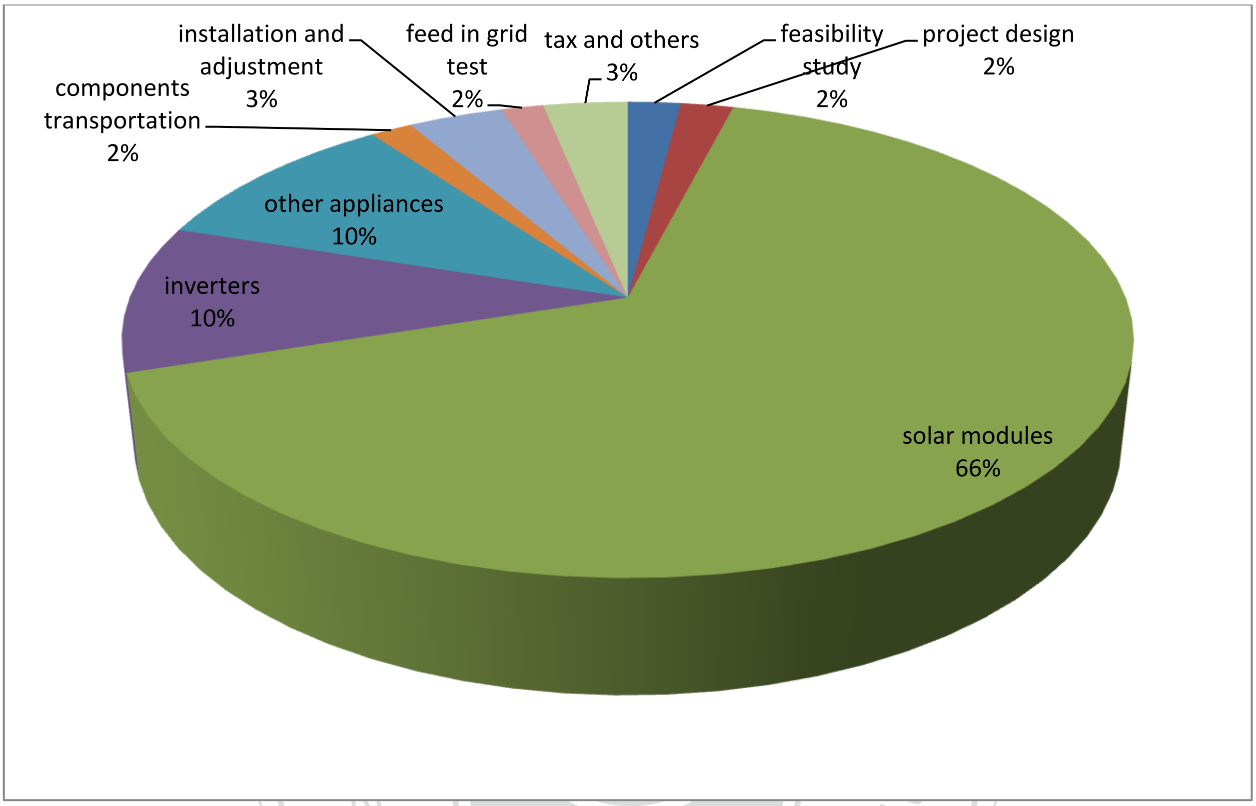
In June 2011 poly-crystalline was sold at around USD 50 which considerably lowered its shared cost of the production line and strengthened the cost structure of China's domestic modules. With growing number of local upstream producers this segment is expected to become more cost competitive in the international market as well. Keeping cell and module prices in a leading position is still crucial for the industry's competitiveness. Low labor, low rent and low electricity fees (which are subsidized by the government) are as much a significant factor today in promoting the industry as they were 5 years ago.

Market prices of modules reflect their production costs, being USD 2.63/W for Chinese modules and average USD 2.96/W outside China in 2009. When braking down the manufacturing chain to sectors it is shown that China's domestic products are sold for an added value that is higher than the one in the international manufacturing sectors. The ingot/wafer sector still lacks behind the international sector, mostly due to lack of economics of scale. The gap is expected to have become smaller by today. As of June 2011 modules manufactured outside of China were averagely priced at USD 1.79/W while Chinese manufacturers offered modules at significant discounts – USD 1.49/W. (Bloomberg, 2011)

3.5. Balance of System Components

Prices for solar modules have dropped by 58% in comparison to the spot rates in 2008, making BOS components' pricing a more crucial part of PV installations. In 2010, BOS costs accounted for approximately 44.8% of utility scale c-Si projects. This percentage is expected to grow to 50.6% by 2012 according to forecasts. (Greentech, 2011) However whereas much attention has been given to the module production line in the last decade, it seems that BOS components have only recently began to receive the attention they deserve.

Figure 3.2 Cost Breakdown of Grid Connected PV System



Source: CREIA, 2007. China Solar PV Report 2007. Pg. 31. China Renewable Energy Industry Association, Greenpeace, European PV Industry Association, WWF

3.5.1. Inverters

Inverters are considered to be the most crucial component of BOS and are critical for the efficiency of a PV system. After the variable DC output is received from the PV modules it is conversed into a utility AC current that can be fed to the grid. The maximum power point tracking (MPPT) technique used in an inverter determines the amount of power injected to the grid from the PV array.

The inverter sector is threatening to become the Industry's new bottleneck with significant shortages reported in 2010. Although considered to be only 10% of a system's installation costs, as it is the second most expensive BOS component developers are increasingly looking for cheaper solutions. With the growing competitiveness in the PV market developers are increasingly focused of higher rates of return on investment rather than on life time of the products.

The Chinese inverter industry has emerged in recent years as a strong alternative to traditional market leaders from Japan and Europe. Due to low manufacturing costs Chinese inverters generally cost USD 0.19-0.20/W while Japanese inverter stand at USD 0.25/W. (Renewable Energy world, 2011) There is however a huge gap in product life as the average lifetime of a Chinese input capacitor is five years. The 10 year warranty provided allow only one replacement, while more expensive inverters are significantly more reliable, lasting up to 20 years. Chinese companies do not want to change the current reliance on low pricing as Eastern Europe also accommodates a developed inverter industry which is strategically located closer to most major markets.

Much like in the cell and module sectors, municipal governments have been actively helping manufacturers reduce costs and achieve high competitive standards. In the past couple of years Chinese manufacturers have entered the European market with a variety of low cost products and a declared goal of EUD 0.06-0.08/W. Due to Bounded Rationality issues these companies are lead by means of imitation and possess low levels of Innovation. As most companies do not list R&D as a high priority, most of the technology transfer happens through joint ventures. Attracted by low production rates, companies are shifting their production factories to China.

The domestic market however relies mostly on domestic firms. Sungrow is China's largest PV inverter manufacturer and has been chosen as the major supplier of the Golden Sun project. Offering a wide range of inverters for small medium and large scale installations Sungrow is utilizing the expertise it has gained in recent years with the expansion of the domestic market and has opened a manufacturing center in Canada. This places the company in a favorable position to penetrate markets in Canada and the U.S. (Sungrow, company website)

The growing strategic importance of inverters in the installation process has spurred companies involved in the module production sector to expand into this sector as well. GCL for example has teamed up on a joint venture with American Satcon Technology Corporation in order to further integrate its manufacturing capabilities. Satcon is expected to provide GCL with the core manufacturing processes and technology for final assembly. (Sustainable Business, 2010)

3.5.2. Batteries

China is home to some of the world's largest lithium battery cell producers, with Suntech acting as the world market leader and other state champions such as BYD, china is a significant force in the solar batteries industry. However, much like the rest of the industry sectors, China has weak battery R&D capabilities and till date hadn't listed any international battery technology patents. Chinese manufacturers suffer from a high rate of production scrap material and have little cooperation with PV systems developers. (China Greentech Initiative, 2011)

There are however government initiatives coming from the ministry of science and technology and the ministry of industry and information which plan future subsidiaries and R&D funding.

As shown above, significant efforts have been made by the municipal governments to promote the c-Si industry in terms of Selection and Bounded Rationality. This has led to an increase in the industry's diversity with a sharp rise of the number of companies involved, different ranges of their size, and a growing number of partnerships and joint ventures. Despite many efforts the up and mid stream sectors still lag behind, mostly due to endogenous selection factors – high technological barriers and lack of industry standards led by a centralized mechanism. The poly-silicon sector, being a niche market, has proven to be a barrier to sector development and has hurt the industry's Innovation standards. Domestic manufacturing of BOS components lags behind the module sectors with much less attention given to it by the government.

Chapter 4 – Future Technologies and R&D

By maintaining itself as a world leader in c-Si production China positioned itself in a favorable place to take advantage of the slowly maturing technology. China's PV industry is currently mostly focused on existing technologies, adopting routines according to foreign demand and imitating foreign best practices and development paths. Over reliance on routines and imitation affects the Diversity of the evolutionary process by limiting the scope of Selection. A healthy sustainable transition requires a diverse scope of performance in terms of incentive policies, industry players and technology.

This chapter will discuss the status of two other developing technologies, thin cells and Concentrating Solar Power (CSP) in the domestic market and industry. Through assessment of its potential development rate in terms of R&D and government support the future technological Diversity of the PV market can be estimated. Although not yet mature and not entirely applicable, these technologies have the potential to create cost reduction in the future.

4.1. Alternative Technologies

There are several other promising technologies apart from the ones used to produce c-Si modules. Thin film is the only other commercial technology that has a market presence apart from c-Si, whereas a relatively fewer number or CSP projects have already been completed. Both technologies will be discussed below from the perspective of Diversity and Innovation.

4.1.1. Thin Film

China has always favored c-Si technology over thin film because of its relative technological simplicity, its proven track record and accessible local supply chain. Thin film is the second most mature technology after c-Si and currently accounts for 10-15% of the world market. Unlike c-Si solar cells, thin films are produced by depositing extremely thin layers of photosensitive material on a low cost glass or stainless steel panel, which requires a significant less amount of silicon.

The main advantages of thin films are their relatively low consumption of raw material as well as their high production efficiency which requires less man power. Thin film cell technology suffers however from lower radiation utility in comparison to c-Si with generally only 6-9% efficiency rates whereas the latter holds a range of 13-20%. Thin film technology holds one significant benefit which is its good performance at high ambient temperature and reduced sensitivity to overheating. The technology roadmap for thin film predicts it to reach a maximum efficiency rate of up to 18% within 20 years of research progress. (IEA, 2010[3]) Thin film is currently a small market however due to its low manufacturing costs is expected to become a more dominant player in the global market.

Thin film or amorphous-Si (the most advanced thin film technology) was introduce in China in the late 1980s but did not account for a large portion of the market until the silicon feedstock shortage. In the time period before the financial crisis industry capacity reached over 100 MW with actual production around 28 MW in 2007. (Zhao et al, 2008) This accounted for over 200% increase from 2006 (12 MW) but only 10% of global production capacity which passed 1 GW at that year. The main driver for the industry was the sky rocketing prices of silicon which had manufacturers compromising on this less mature technology. Over 55% of manufacturing capacity at the time was located in the U.S with Europe accounting for almost 20% and the rest distributed between Japan and China. (Grama, 2007)

Chinese manufacturers are now putting in more resources into R&D and partnering with manufacturing equipment suppliers in order to further lower thin film production costs. Through technology improvements and developing the domestic supply chain manufacturers are expected to cut down production costs from RMB 8/W to RMB 4/W by 2012. (Renewable Energy World, 2011)

Thin film has a strategic importance to China as it has the potential to threaten the dominant position of the existing industry. With manufacturers overseas complaining about the uneven competition with Chinese firms due to government assistance and the production sites migration to china, the U.S government has made thin film technology a national priority.

At the end of 2008 seven companies were accounted for over 90% of the domestic industry capacity which reached over 200 MW (actual production stood at 37.9) (CTCRP, 2009) Backed by government subsidies, China’s industry leaders have started expanding their manufacturing capacity. Astronergy has declared expanding their production to around 1000 MW by 2012, with ENN Solar, QS Solar and Best Solar expected to complete over 500 MW production capacity plants. China’s production capacity has already exceeded 2 GW and is expected to exceed 4.7 GW by 2013.

The central government is playing of course a major role in the promotion of the domestic industry with financial packages designed to further increase capacity. In June 2011, Anwell technologies has secured a total of RMB 700 million in long term funding to its subsidiary in Henen province for thin film manufacturing expansion. Anwell is expected to complete a 1.5 GW manufacturing plant within 5 years. (Solarbuzz, June 21st, 2011)

Thin film is expected to become a leading technology for large scale solar farm projects in china's northwestern provinces as well as in Inner Mongolia due to its vast available land and harsh climate conditions, where it shows better results. In fact the domestic market is expected to account for one third of total thin film sales in 2012 with Europe and the U.S markets accounting for a third each. (Renewable Energy World, 2009) This forecast might be the indication that the thin film market is on a more balanced and sustainable path of development than the c-Si market has been so far. The demand for thin film is also expected to increase the development of China's BIPV projects as this form of deployment is easy to use in this technology.

Chinese thin film producers will find it difficult achieving the same rates of success as the c-Si industry does due to their still rather limited production scale and mostly because of shortage in advanced technology and heavy reliance on imported equipment and raw materials. The purchase of expensive equipment makes upfront investment ten times higher than that of silicon module producers. For example, even after producing 70% of its own production equipment (which is a rare achievement in the Chinese industry), Shenzhen Topray had a gross margin of only 23.8% of First Solar's gross margin. (First Solar being the industry leader) (Renewable Energy World, 2009) While small and medium scale companies have to settle for much smaller margins, they have also to deal with the recent silicon price decrease as a result of the financial crisis. Government subsidies are more important than ever in order for the sector to continue developing.

4.1.2. Concentrating Solar Power

The discussion on Concentrating Solar Power (CSP) lies within a different aspect of the evolutionary model than thin film technology. Whereas thin film accounts for a significant size of the total market (although is further away from reaching maturity than c-Si technology) CSP is still considered a future experimental technology. As there are few routines and imitations that could be followed in this sector, Innovation plays a more decisive role in determining its potential success.

CSP is a solar thermal concentrating technology. It differs from module PV technologies in the sense that in doesn't convert sunlight directly into electricity but converts it into thermal energy first, then uses a traditional turbine to convert heat into electricity. The most mature CSP technology is the parabolic trough, with an accumulate 667.4 MW installed at the end of 2009 and an additional 2133 MW under construction in 2010, mostly in Spain.

The first significant CSP project in china was through collaboration between Hehai University and Israel Weizman Institute in which a 75 KW solar/oil tower hybrid demo system has successfully kept running for two days in Nanjing. Another 1 MW tower was completed in Beijing at the end of 2010, funded by the Ministry of Science and Technology and the Beijing Municipal Science and Technology commission. (Chinese Academy of Science, 2009)

Private investors are particularly excited about this new energy sector and several venture projects have already set off. Tianjing Solar has constructed a 146 MW solar demo in Tianjing in 2009 in collaboration with U.S SETC and are planning to develop more projects in Lasa, Tibet. These projects are designed to promote an innovative dish technique that presents an independent power production system which can enable continuous power production running without backup of fuel.

Investors such as SETC are hoping that CSP will receive the same warm support c-Si and thin film technologies have received in China. Being the first developers in the industry this investors are placing themselves in key sectors which might help them to position themselves as future domestic and global suppliers. However unlike the previous technologies, CSP is a young technology that hasn't proven itself commercially and is far from maturity. The technology still needs to acquire the governments' support which in this case cannot be taken for granted.

The five provinces that have shown high potential for CSP technology are of course the northwestern provinces and Inner Mongolia, all of which are remote and far away from the central grid. Nothing new here, however unlike PV technology fields CSP systems require more maintenance and on site supervision. These high numbers of professional workers and engineers will be hard to recruit and are not easily found in remote areas.

According to senior government energy policy makers CSP is not deemed as very suitable for China. (NYT, January 8th, 2010) CSP systems require high amounts of cheap water in order to condense the steam after it has been used to generate electricity. Many provinces in China suffer from growing water shortages and the bare deserts in the west are no exception. In order for CSP projects to succeed alternative cooling technologies need to be adopted.

Never the less world scale projects are already underway. Penglai Electric, a privately owned Chinese electric power manufacturer has reached an agreement to build at least 2 GW of solar thermal plants in the next ten years. Collaborating with U.S eSolar the company has already started building a 92 MW project and is expected to develop mostly in Inner Mongolia. eSolar is expected to provide CSP tower technology which has demonstrated commercial maturity. (PVtech, January 11th, 2010) Most of the component sourcing is already feasible domestically which is expected to lower costs by over 40% in comparison to overseas. The construction process itself is the major technological barrier in the CSP market, where Chinese developers still need to collaborate with international players.

If installed properly, CSP has proven to possess the greatest efficiency rate among the technologies presented in this paper, with 25-35% efficiency potential. Industrialization maximum efficiency is expected to reach 40%, twice as much than thin film's CIGS technology which is the future leader in its field. CSP can and should become a part of China's future solar mix, adding to the market Diversity and lowering solar electricity costs. Having proven as a more stable technology in terms of electricity flow CSP could play a role in stabilizing the grid current and increase solar cell installation areas.

As government support is lacking the future of the sector lies within venture capital and private investors as means to promote Innovation. Just like c-Si and thin film technology China does not seem to be ready to position itself as a world innovative leader. The projects described above in Nanjing and Beijing were the first of their kind in Asia. Moreover, over 15 research projects have been commenced or are underway in national universities – many including international collaboration with world class institutions. (Chinese Academy of Science, 2009) However the lack of support for commercial projects makes it hard for technologies to be tested. It will take overcoming issues of Bounded Rationality in order for this future technology to further develop in the coming years.

4.2. Research and Development

The Chinese government has devoted a great amount of resources to R&D in the energy sector. Holding the world's largest R&D budget as of 2008, China has given particular attention to themes such as clean coal technology, hydrogen and fuel cell technology, energy efficiency and renewable energy. Most of the funding is retrieved from the Ministry of Science and Technology, however provincial and municipal governments have also provided support.

Although research on PV solar cells technology has been on China's agenda since the beginning of the reform era the work was concentrated primarily in government research institutes. The industry remained a decade behind the world standard until the big global market development in the 2000s. With most start ups remain with few resources after building their manufacturing factories R&D relied mostly on domestic as well as multi and bilateral loans and grant funding. Technologies were mostly purchased and companies were occupied with developing the domestic market for necessary raw materials. (Dewey &LeBoeuf LLP, 2010)

The situation changed with the emergence of the national champions in the mid 2000s. Current market leaders have forced domestic competitors and suppliers to match quality and prices and have taken the industry ahead in terms of innovation. The first company to appear was Suntech, which as mentioned above relied on the expertise its founder acquired abroad. Suntech has been the first company to develop its own technology to the extent that it managed to compete with leading global brands not only in terms of price but also quality. Suntech was founded with the help of a municipal government, and received direct governmental support for its R&D efforts.

Government support in R&D through solar manufacturers reflects an understanding that solar companies must remain innovation leaders in order to survive. The Chinese government supports Suntech's technology indirectly through its funds as the company has been acquiring smaller solar technology companies with the potential to improve its PV performance. Suntech has also worked to promote its technology by teaming up with universities and opening research centers overseas in order to diffuse knowledge and skills back to the Chinese industry. In 2010 it has partnered with Melbourne's Swinburne University of Technology. The collaboration has opened the Victoria-Suntech Advanced Solar Facility which is currently developing advanced third generation energy cells. (Invest Victoria, 2010)

The extent to which the government is involved in promoting R&D should not be over emphasized. LDK has opened its R&D center in Jiangxi province in 2007 and has since undertaken over 100 R&D projects. (LDK, 2011) Out of these projects only seven were government supported by the states whereas the rest were privately subsidized or collaboration with overseas organizations. In 2010 LDK signed a memory of understanding with the U.S department of energy's National Renewable Energy Laboratory for collaborative research and development activities related to silicon materials and PV devices. (PVtech, September 20th, 2010)

Three national programs have played an active role in promoting solar R&D in China. The first one, called the 863 program, aims at rendering China independent of financial obligations for foreign technologies. The program was designed to diversify china's R&D efforts but renewable energy did not become a part of the program until the tenth five year plan (2001-5).

Between 2006 and 2010 the program has funded research on various fields including disbursed BIPV, CPV, on grid large-scale PV in deserts, and thin-film. Today the program still funds world class research projects in the solar sector. On March 2011 Shanghai Chaori Solar announced a strategic cooperation agreement with PVON Solar, China Science Institute Electrical Research Department and Shanghai Jiaotong University Solar Research Institute to develop production methods for thin film and c-Si. The project is expected to develop c-Si cells with 20% efficiency rate in the coming years as well as to promote thin film efficiency rate. (PVON, 2011)

The second program, named the 973 program or the National Basic Research program, was launched in 1997 to support more basic R&D projects. The China Academy of sciences and Nankai University received support from the program for a 5 year period until 2010 in which they conducted research of low cost and long life thin film PV cells. The third program, called the Key Technologies R&D program, was created in 1981. Up to 2010 the program mostly disbursed funds for R&D of c-Si technology and equipment.

These three programs have disbursed between 2006 and 2010 a bit more than EUD 20 million, with the 863 program accounting for more than 75% of the funding budget. As a comparison, two national R&D programs in Germany have funded solar R&D projects in over EUD 60 million in 2008 alone. (Climate Policy Initiative, 2011) China has yet a long way to go when it comes to national R&D funding programs. It still lacks professional research institutes and trained researchers which could take advantage of a bigger R&D budget. The national budget allocated to programs such as the 863 and the 973 are expected to grow with the growth of its research institutes.

Having limited options to work with at home, china turned to the international community for R&D developments. In 2007 the NDRC and the Ministry of Science and Technology (MOST) have initiated the International Science and Technology Cooperation Program in Renewable Energy. The program was aimed at diversifying the source of the nation's technology imports and to expedite technology transfer from other countries. In the years since china has signed 103 agreements with 97 countries, many of which relate to renewable energy development. Solar and PV power generation received a special priority field in these collaborations.

At the end of 2009 China and the U.S announced the launch of a new U.S-China Renewable Energy Partnership. The two countries have started working together on a road map for wide spread renewable energy deployment in both countries. The partnership will provide technical and analytical resources to states and regions in both countries, and will facilitate partnerships to share experience and best practices. A new U.S-China Renewable Energy Forum will be held annually, rotating between the two countries. (White house, 2009)

This agreement has been the official starting point for a wave of collaborations and joined activities between Chinese and U.S companies holding a joint mission of mutual learning and development.

The best example would be the collaboration of First Solar, which is traditionally a competitor of the Chinese PV industry, with a domestic player. In May 2011 First Solar and China Power International New Energy have signed a strategic cooperation framework agreement, under which they will work on PV projects in China and the U.S. (PV Magazine, 2011) The companies are expected to help each other identify project opportunities in both countries and will share practical market experience along with technical knowhow. First Solar has also joined the U.S clean energy business mission to China in order to learn about China's industrial demands and about market development opportunities. As mentioned in the beginning of the paper First solar was chosen as the leading collaborator bringing experience and technology in developing the ambitious 2 GW project in Ordos city.

Another form of R&D support comes in the form of exemption of import tax and value added tax for R&D institutions. This applies to imports by foreign invested R&D institutions and domestic R&D institutions alike. Lured by favorable R&D conditions Applies Materials, one of the world's leading PV equipment developer, has built in Xi'an one of the world's largest solar research facility. Being the largest nongovernmental research facility in the world, the complex has a laboratory as well as an entire thin film manufacturing line and a complete c-Si pilot process. Employees in the center are working with local suppliers and are testing new materials and tools in order to come up with new cost saving technologies. (Applied Materials)

Conclusion

This paper presents a macro analysis of China's transition efforts to utilization of solar energy using PV technology. A transition of this scale does not merely include an operational aspect but also an institutional and mental change. It requires long term planning, adaptation and a balanced utilization of resources.

The evolutionary economics theory presents us with a dynamic analytical approach to transition using a framework that consists of six primary elements. This paper presents a review of China's efforts on 'going solar' arranged by these six elements. The overall goal of transition to solar power is to integrate solar PV energy in the national grid with a competitive price that would be able to challenge the present conventional energy production methods. A list of criteria has been presented in the beginning of the paper that are regarded as a condition to grid parity success. This concluding chapter will present the status of these key criteria within the evolutionary development framework.

Bounded rationality - Bounded rationality is probably the most critical aspect of the evolutionary framework. The transition to renewable energy is full of question marks concerning the future of the technology, best utilization techniques and the development of the market. Investors in the market have a short time horizon and ROI is the driving force of decision making. Bounded Rationality has a technological and financial aspect which the government had to overcome.

We have seen that China has by no means been a market leader in the last decade. The real growth in the Chinese market was spurred by a proven technological success in overseas markets based on lessons learned and the adaptation of best practices from abroad. The Chinese PV market has been conservative and the fear that technology hasn't yet matured in China has had a restraining effect.

This cautiousness is also reflected in government legislation concerning FID and promoting price competitiveness of PV. For over 5 years developers have been waiting for a FID to be presented in the PV market. The wind energy market has enjoyed an FID for 4 years now and has undergone substantial development however PV developers are still waiting for this financial aid. Without a coherent law the market will continue to suffer from uneven competition.

The Dunhuang project, expected to be completed in 2012, is expected to become an act of confidence in the market and reduce investors' and developers' Bounded Rationality. As we have seen, future technologies suffer from similar problems. The case of the collaboration of Penglai and eSolar in promoting CSP is an example of private initiative in overcoming the government's

Bounded Rationality. Bounded rationality is about making the best decision within limited resources and time frame. So far CSP has not received the attention it might deserve.

Bounded rationality has also been the reason for many companies to cut costs by using cheaper raw materials and simple technologies. In the short term this would make PV a feasible investment but these decisions pull the industry back and lower its production standards.

Diversity - Being the core element of an evolutionary transition, diversity can serve as a quantifying measure for the fitness of the transition. A sustainable transition will include a broad range of players from the industry and the market, will utilize different technologies and include a variety of institutions.

As shown above in recent years the PV market segmentation has reached a more ideal range of diversity with commercial large scale deployments entering the market. With much attention given to BIPV this two segments are expected to grow and become the market leaders. Current incentive programs have prevented from most private companies from entering the market which created a homogenous mix of developers. As most developers are state sponsored technology inflow is limited which decreases cross fertilization processes in the industry and within the Innovative environment.

Cross fertilization refers not only to innovation but also to price competitiveness and price reduction of PV. The more companies become involved in the market the more knowhow and best practices there is to share. These affect the system price, especially the actual installation procedure which accounts for a growing percentage of the total project cost. It affects production optimization and leads to a limited range of industry and deployment standards.

As shown above, the domestic PV industry is the driving force behind China's energy transition. The industry is currently focused on a single technology and is mostly located in the downstream sectors of it. As the case is in the silicon purification and the wafer/ingot sectors only one dominant technology prevails and the industry is dependant of technology and raw material imports for production diversification and manufacturing equipment.

Innovation - Innovation is the weak point of China's solar transition. The low amount of funds dedicated to R&D in comparison to Germany, being the world leader in this aspect, reflects the absence of a broad professional educational system. China has a few world class research centers with the China Academy of sciences leading the demand for growing government attention to PV research. However many provinces still miss thousands of engineers and scientists that could build the elements to the country's solar transition.

China has to settle with attracting overseas innovation. While it has been successful in attracting world class brands in moving their manufacturing factories to China, research centers such as the one built by Applied Materials is more of an exception. The real success China has had concerning Innovation is by encouraging its local champions such as Suntech and LDK into developing their own research standards. These companies have reached a high standard of production and are a future asset in PV price reduction schemes.

Selection - This has been the most successful element of China's effort so far. Selection refers to measures taken to ensure that investors and developers select PV technology over traditional technologies. China has become a major force in the PV industry due to various government incentives and regulations. The industry has obtained economy of scale which is vital for price reduction. Many of the leading companies have made progress in production optimization as a result of economies of scale.

The central and provincial governments have been very supportive of market expansion in the past two years. The golden sun program and other subsidy programs have boosted domestic deployment rate and raised the awareness for PV. It is for these measures of Selection that China has become the world's future PV market.

Path Dependence and Lock In - Here lies China's biggest challenge. Not enough has been done to promote the deployment of smart grid and regulate the connection of PV electricity plants to the national grid. As a part of its FID regulation a compensation mechanism needs to be designed for grid operators. Technical standards need to be adopted for the deployment of PV plants in order to assure connection optimization.

Electricity pricing is yet another pressing issue. Conventional electricity is subsidized by the government in order to promote the domestic industry. If PV electricity is to reach grid parity within the coming 20-30 years the central government will need to gradually lower its subsidy level. This is a great future challenge to the country's industry sector as well to its electricity sector.

Co-evolution - The two main technologies that need to show strong technological development along with the PV module technology are inverters and batteries. As shown above, the inverter technology has enjoyed similar benefits as the module industry has. China has reached satisfactory standards in this industry. Much like the module industry it still highly depends on overseas R&D and innovation standards, which for the time being still prevent BOS costs from declining significantly. China's weak battery R&D capabilities present a similar problem. Both industries have been categorized as national priority industries, however due to low innovative capabilities BOS prices are expected to remain relatively high in the near future.

This paper was prepared with the purpose of providing an in depth multi-level analysis of solar PV transition. As mentioned above, one cannot predict the prospects of a renewable transition without understanding both the market and industry along with the governmental attention both receive. Until the REL was passed in 2005 government focus toward renewable energy and solar PV were regarded mostly as an experimental field. We have seen that in recent years much attention was paid on promoting the industry, with market promotion only beginning in the last two years.

Using the six elements of evolutionary development as an analysis framework has shown that China is well positioned towards a transition to solar PV in some elements more than others. The Chinese government has made an impressive effort in promoting solar PV through subsidies and considering the amount of risk involved in inexperienced promotion of PV utilities they have managed to cope with issues of Bounded Rationality quite successfully. Successful results concerning the Dunhuang project will lessen Bounded Rationality effects and is expected to attract more developers and investors to the market.

Policy has so far focused mostly on promoting PV energy by focusing on Selection, mostly with direct subsidies and direct provincial support. This approach is not sustainable in the long run as it does not allocate the responsibility to create efficient installments to market developers. Subsidies are small in scope and while they are a great promotional tool to the sector, only a balanced mechanism such as FID could promise a large scale long term development of the market. China should aspire to allocate more focus towards Bounded Rationality issues in the coming years.

China also needs to attend to issues of Diversity and Innovation as they threaten to hold back the industry and market development in the future. Lack of independent R&D driven by market needs is felt within the elements of Diversity, Path Development and Lock Ins as well as in Co-evolution. Diversity suffers the most from the lack in Innovation as can be seen in sectors of the c-Si industry and within potential future technologies. As the current market is yet immature the effects of lack of Diversity and Innovation are found in it to a lower extent and are expected to rise in the near future.

Despite China's obvious shortcomings, this research has shown that the country is taking positive first steps towards a rather sustainable energy transition. The next challenge of the solar sector will be the future cooperation of the market and industry. China is planning on relying heavily on domestic support for its market expansion. However industry players have not sounded too keen on shifting attention to their domestic market. As a Suntech high ranking director said, as 98% of production going abroad with a higher margin than is to be expected at home, manufacturers hope the government will not impose a minimum quota of domestic supply for future projects. The solar PV sector will have to better define its goals and create a mutual working environment in the future in order to strengthen cooperation between its different players.

This research was prepared as an overall guide to the forces and challenges in today’s solar PV energy sector in China. It is aimed at guiding both investors and policy makers in hope that their decisions will be aimed at sustainably promoting the sector in its future path to grid parity. The renewable energy sector in general and solar PV specifically require time and a focus on long term strategic planning. The evolutionary approach is therefore unique in its broad vision and the attention it gives to a variety of short and long term issues.

Using a unique analysis framework this research has shown the relations between government and industry and technology. Unlike most studies which try to depict an overall linear progress in the solar sector, this paper presents a more balanced picture. As shown above, several elements are at work in the promotion of energy transition. It is not a simple matter of summing the effectiveness of all elements that can portray a development path. Understanding the different interactions among them creates a more complete comprehension and serves as a basis for a more balanced decision making procedure. It is here where the importance and uniqueness of the paper lies.

This paper has only presented a general analysis of the six evolutionary elements in an attempt to present a long term overview of the sector. In the future more research is yet to be done on the specific elements and their interaction. In China’s case, issues of Bounded rationality and Innovation are particularly urgent and a more in depth analysis will contribute greatly to our knowledge and understanding of the industry. This form of analysis could also be applied in other sectors in the renewable energy sector such as wind and biofuels.

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