MASTERARBEIT

Titel der Masterarbeit

Solar Energy Potential in China, South Korea and Japan

Verfasser

Seunghwan Jung

angestrebter akademischer Grad

Master of Arts (MA)

Wien, 2014

Studienkennzahl lt. Studienblatt:	A 066 864
Studienrichtung lt. Studienblatt:	Masterstudium Wirtschaft und Gesellschaft Ostasiens
Betreuer:	Prof. Dr. Rüdiger Frank

Acknowledgements

I would like to acknowledge my supervisor Dr. Rüdiger Frank, for his support and advice with deep insights from the beginning of the master program and my master thesis. I also thank my classmates and ECOS members as I really enjoyed sharing our opinions and spending time together. Especially, I was pleased and felt lucky that I was part of the AKSE conference 2014.

I appreciate my family members in Seoul and Vancouver. Without my family member's patience and understanding, I could not start and finish my studies.

부모님 그리고 정승은, 허세준, 친지분들, 친구들께 감사드립니다. 덕분에 석사과정을 잘 마무리 할 수 있었습니다. 항상 제 의견 존중해주시고, 힘든 일 있을 때 마다 격려해주셔서 감사합니다.

I would also like to thank Georg and Maria-Christina Brunauer's support. Thanks to your technical and general advice and help from the beginning of my paper, this thesis is well finished. I also feel thankful to Gottfried, Günter, Christine, and Michael Fenböck for your warm encouragement.

Lastly, but mostly I am very grateful to my wife Marianne Jung, who brought me to Vienna and changed my life. I really appreciate that we can share and discuss about studies as well as matters in our life.

Contents

1. Introduction

A sustainable development receives attention all over the world. The United Nations World Commission on Environment and Development (WCED) defines 'sustainable development' as *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Brundtland Commission, 1987). The principles of sustainable development focus on economic development, social development and environment protection. In his speech at the Austrian Academy of Sciences on March 12, 2014, Jeffrey Sachs stressed that the main strategies for promoting a sustainable development are investing in young people, in sustainable technologies and in deep decarbonization (Sachs, 2014).

Energy has played an indispensable role in human-being's history. It is no exaggeration to say that people cannot live without energy. Energy contributes not only to mankind's survival but also to economic development. The invention of James Watt's steam engine by thermal energy to kinetic energy brought forth the industrial revolution and deeply changed peoples' life style. Due to its significance, energy also plays an essential part in politics causing many wars because of natural resources. In East Asia, the terminology 'energy security' is often used among politicians and treated as diplomatic means. The facts that China is the most energy-consuming and -demanding country in the world, that South Korea depends on over 95 percent on energy imports, and that Japan suffers from the Fukushima nuclear power plant disaster, show why energy security is imperative in East Asia.

One-third of carbon dioxide emission in the world occurs in East Asia (Olivier et al. 2013). Global warming and a destructed environment are caused by such emission. In light of that, renewable energy is regarded as a significant alternative due to its eternity and cleanness. In addition, the improvement of sustainable energy could lead to economic development such as job creation, growth of manufacturing infrastructures, ancillary commerce and tax revenues (Yu, 2013). Each country in East Asia realized the importance of renewable energy. The matters of climate change, economic competitiveness, pollution, and human livelihood draw to promote renewable energy in China (Lo, 2013). In South Korea, power outages as well as energy security and reducing greenhouse gas emission are main reasons for developing renewables (Oh, 2012). The aforementioned global warming prevention and especially the latest nuclear accident led people to consider alternative energy sources in Japan (ISEP- Institute for Sustainable Energy Policies, 2013).

The definition of renewable energy is different in each country. One of the well-known international organizations for renewable energy, the International Energy Agency (IEA) defines renewable energy as follows:

> *Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resources (IEA, 2008:vii).*

In 2005, the People's Republic of China promulgated 'the renewable energy law'. In article 2 of the law, the definition of renewable energy is described as follows:

For the purposes of this Law, renewable energy means non-fossil energy, including wind energy, solar energy, water energy, biomass energy, geothermal energy and ocean energy. Application of this Law to hydropower generation shall be subject to regulation by energy administration department under the State Council and approval by the State Council. This Law is not applicable to utilization of straw, firewood, excrement, etc. through direct burning in low-efficiency stove (National People's Congress (NPC), 2005).

The Republic of Korea enacted the 'Act on the promotion of the development and use of new and renewable sources of energy' in 2005 and finally amended it in 2014. Following is the definition of renewable energy in article 2 of the law.

The term "new energy and renewable energy" (hereinafter referred to as "new and renewable energy") means energy resources converted from existing fossil fuel resources or renewable energy sources, including the sun, water, geothermal heat, precipitation, and bio-organisms, which fall under any of the following items: (a) Solar energy; (b) Bio energy converted from biological resources, which falls within the criteria and range prescribed by Presidential Decree; (c) Wind power;(d) Water power;(e) Fuel cells;(f) Energy from liquefied or gasified coal, and from gasified heavy residual oil, which falls within the criteria and scope prescribed by Presidential Decree;(g) Energy from the ocean;(h) Energy from waste treatment, which falls within the criteria and scope prescribed by Presidential Decree;(i) Geothermal energy;(j) Hydrogenous energy; and (k) Sources of energy prescribed by Presidential Decree, other than petroleum, coal, nuclear power, or natural gas; (MOLEG, 2011)

Japan introduced the 'Act on the Promotion of New Energy Usage' in 1997. In Article 2, the new energy is defined as *a type of energy that is becoming technologically viable and essential as an alternative to oil (Japanese Law Translation, 2009; Ohira 2006).* Renewable energies in Japan are hydro power, geothermal, photovoltaic, wind energy, biomass conversion, solar thermal, small & micro hydro, waste-derived energy, ice & snow utilization, and ocean energy (Ohira 2006; JCRE – Japan Council for Renewable Energy, 2014a)

The classification of (new) renewable energy in each country is shown in the below table. Solar energy is confirmed as a renewable energy by East Asia countries and the IEA.

Table 1. Classification of renewable energy by countries[1]

	Solar	Wind	Hydro	Geo thermal	Bio mass	Waste	Ocean	Hydro genous energy	Fuel cell	Coal gasific ation
IEA	O	O	O	O	O	-	O	O	-	-
China	O	O	∆	O	O	-	O	-	-	-
Korea	O	O	O	O	O	O	O	O	O	O
Japan	O	O	O	O	O	∆	O	-	-	-

Source: Lee SH (2014: 74)

Solar energy is defined as *radiant light and heat from the sun and is harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar architecture and artificial photosynthesis (IEA, 2011a).* Solar energy is an ultimate renewable and zero greenhouse or toxic gasses-emission energy source. Solangi et al. (2011) point out the advantages of solar energy: Reclamation of degraded land, Reduction of transmission lines from electricity grids, Improvement of quality of water resources, Increase of regional/national energy independence, Diversification and security of energy supply, and acceleration of rural electrification in developing countries. What is more, there is no noise,

[1] O is confirmed. ∆ is partly confirmed.

radioactivity, danger of explosion and it is convenient to maintain the system (KEMCO - Korea Energy Management Corporation, 2008). On the other hand, the generating cost is still high, the quantity of generation per day is not stable, and the generating time is limited by sunshine duration especially during night and raining time (Nam and Oh, 2006).

The amount of solar energy reaching the earth's surface within an hour is equivalent to the amount of the energy that human being consumes for one year (Gaudiana, 2010). It is assessed that the theoretical potential of solar energy is 3.9 million exajoules (EJ) per year and the technical potential is more than 1,600 exajoules per year (Johannsson et al. 2004). It is expected that the total generation quantity of solar energy will exceed that of hydro's in 2020 and that of wind's in 2030 (Ahn, 2013).

Table 2. Realizable limit, generation limit of renewable energy

Energy sources	Realizable limit (MW)	Generation limit (MW)			
		2015	2020	2025	2030
Nuclear	-	23,953	30,532	37,278	43,926
Hydro	23,821	2,319	3,138	3,439	3,513
Wind	57,340	1,882	6,053	11,468	15,257
Solar	**2,071,838**	**2,304**	**5,609**	**10,717**	**17,865**
Biomass	14,896	817	1,423	2,062	2,809

Source: Ahn (2013); KEMCO (2010)

1.1. Research questions & Relevance

The definition of renewable energy potential has been explored by many researchers (Hoogwijk, 2008; Resch et al. 2008; Kreycik, 2010; Verbruggen, 2010; Krewitt, 2008). Several studies have already analyzed the global level of renewable energy potential (Hoogwijk, 2008; Resch et al. 2008; Krewitt, 2008). In addition, the theoretical potential of solar energy (Tang et al. 2011; Li et al. 2010; Jo, 2006; Kudo, 2010) and the economic potential (Ouyang et al. 2014; Kim and Chang, 2012) have been examined as well. However, scholarly research still lacks a multi-dimensional perspective on the potential of solar energy in East Asia. That is why this thesis takes such a perspective on three East Asian countries by answering the following research questions:

- How large is the solar energy potential in China, South Korea and Japan?
- What is the theoretical and economic potential of solar energy in East Asia?
- How is the solar energy market situation in East Asia?

Thus, this thesis specifically adds to scientific discourse by investigating presumably the most important source of renewable energy: facing increasingly adverse effects of climate change, the search for the reduction of greenhouse gas emissions and for sustainable growth strategies raises the advancement of renewable energy-based technologies. In order to contribute to scholarly research as a pathway to sustainable development in East Asia, this thesis examines the potential of solar energy in China, South Korea, and Japan, purposefully focusing on three most important economies in East Asia. Overall, a detailed picture on the potential of solar energy in China, South Korea, and Japan will be presented.

1.2. Theoretical framework and methodology

There are several studies analyzing renewable energy potential that are relevant for this examination. Kreycik et al. (2010) mention four basic dimensions to be used as a framework for renewable energy potential studies: Resources, Technology, Economy, and Market. The first dimension, resources, is an assessment of the theoretically renewable resources in a region. The maximum amount of feasible renewable energy, reduced by technical and land limitation is equal to the technical potential. The economic potential is an estimation of cost and cost-competitiveness of technologies. The market potential can be assessed by market acceptance considerations such as demand, supply, commodity prices, regulations, and incentives.

Stangeland (2007) divides renewable energy potential into four categories: Theoretical, Technical, Realistic, and Realizable potential. The theoretical potential presents an entire physical energy amount given source. The technical potential characterizes the amount of energy that current technologies can utilize. The realistic potential is the amount that can be realized after considering social acceptance, environmental factors and area conflicts. The realizable potential is the energy which relies on economic conditions and global market production capacity.

Hoogwijk and Graus (2008) present five dimensions of renewable energy potential: Theoretical, Geographical, Technical, Economical, and Market. They state that the theoretical potential is the highest level of potential which are considered as restrictions from natural and climatic parameters. Geographical potential is the limitation by geographical locations and technical restrictions like conversion efficiencies limit the technical potential. The market potential takes into account the demand for energy, the competing technologies, the costs and subsidies of renewable energy sources, and the barriers.

Krewitt et al. (2008) also developed five dimensions of capturing the renewable energy potential: Theoretical, Technical, Economic, Deployment, and Demand potential. They define theoretical potential as the natural and climatic parameters like solar irradiation. Geographical restrictions such as land use and structural constraints are regarded as influencing the technical potential. Economic potential takes into account to competitive costs. The structure of the existing supply system, the deployment of energy demand, energy policy targets, and instruments in place are considered as the deployment potential. Demand potential means the point when the economic potential may exceed the energy demand by increasing competitiveness of renewable energies.

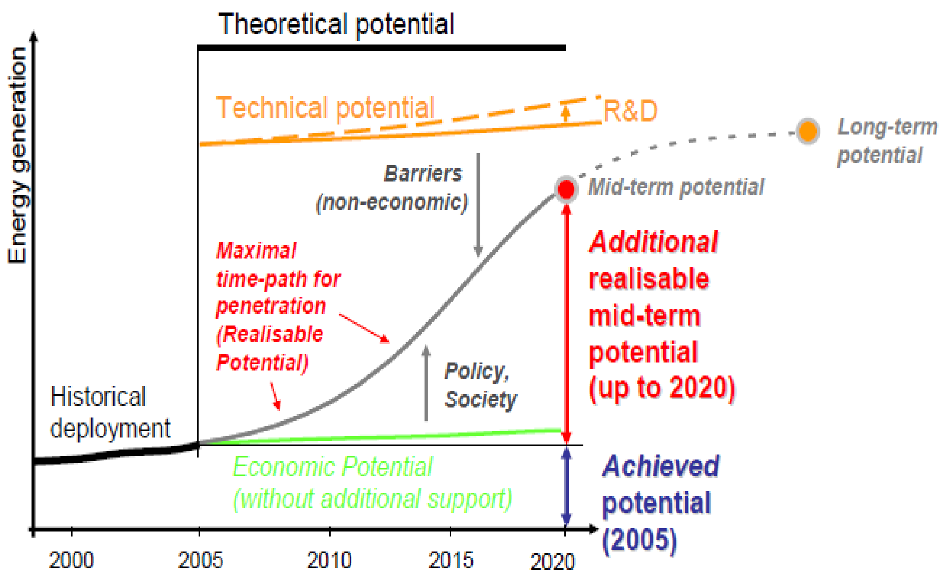
Resch et al. (2008) point out a four-dimensional potential: Theoretical, Technical, Realizable, and Mid-Term. Theoretical potential should take into account the physical parameters. Efficiencies of conversion technologies and technical limitations can be considered the technical potential. Market growth rates and planning constraints are the realizable potential. Mid-term potential means the realizable potential in a year.

Kofoed-Wiuff et al. (2006) outline the global resource potential of renewable energy resources: Current use, Technical potential, and Theoretical potential.

As a framework of analysis, the structure developed by Kreycik et al. will be used, focusing on the **four dimensions of resource potential, technical potential, economic- and**

market potential. More specifically, the resource potential focuses on the solar radiation quantity and the time of availability (i.e. sunshine duration). The technical dimension covers the calculated technical potential by regional area. The economic potential shows the levelized costs of electricity (LCOE) of selected energy sources in comparison to solar PV. Finally, the analysis of the market potential includes a review of the market potential, the development of demand and supply as well as the trends of energy use, current prices and market players, and a viability analysis of the policy framework in all three countries. Figure 1 below shows the presented dimensions of energy potential in a graph. The theoretical potential or total amount of resources is being reduced by the technical potential, further reduced by economic and market potential.

Figure 1. Methodology for the definition of renewable energy potentials



Source: Resch et al. (2008: 4)

The analysis is based on extensive literature analysis and quantitative data analysis of statistics provided by international organizations, national statistics, and scholarly articles. Data was collected through desk research as well as direct investigation at Chinese and South Korean national libraries, the Expo Solar PV Conference 2014 in South Korea and the International Conference on Concentrating Solar Power and Chemical Energy Systems in China (SolarPACES 2014).

In the section on **resource potential**, the solar radiation quantity by region in each country will be explored. We will conclude that the more quantity of solar radiation exists in those locations, the more potential of solar energy we have. Similarly, it will be concluded that the more time of sunshine duration is available in those areas, the more solar energy potential we have.

The following equations form the basis for the calculations and analyses: The **technical potential** of solar energy is the reduced amount of energy by technical limitation from the theoretical and geographical potential (Fig. 1). The technical potential of solar energy can be calculated by the following equation and assumptions (Farooq and Kumar, 2013; Hoogwijk, 2004; Defaix et al. 2012). The technical potential in each country will be assessed with the formula and assumptions.

$$E = A \times Gpoa \times \eta \times PR \tag{1}$$

Where, E is the annual electricity production (kWh/yr), A is the usable roof or facade surface (km^2), G_{POA} the average yearly irradiation in the tilted horizontal or vertical plane of array (POA) per square meter (kWh/m2/yr), η the average module efficiency (%) and PR is the system performance ratio (Defaix et al. 2012: 2646)

Assumptions:

- Crystalline silicon technology is chosen because of its higher efficiency and higher market share (Farooq and Kumar, 2013; Teske and Masson, 2011; Makrides, 2010)
- The average efficiency of module is 15%. In this study, we assume efficiency of PV system as 15 % (Farooq and Kumar, 2013)
- The suitable area is completely covered by PV modules (Hoogwijk, 2004)
- The system performance ratio of the best system is between 0.66 and 0.85. In this paper, we assume the performance ratio is 80 % (Hoogwijk, 2004; Defaix et al. 2012)
- The area of building sites, suitable for installing PV modules, lies in between 9.2 % to 35.8 % in South Korea (= 16.2 % on average). In lack of numbers for China, we therefore calculate with 15 % of available rooftop area in Chinese provinces.

To analyze the **economic dimension** of solar energy, the levelized cost of electricity (LCOE) will be used. The economic potential of solar energy in China, South Korea and Japan will therefore be expressed in terms of the LCOE – data which is offered by the International Energy Agency (IEA), the World Bank, and scientific articles. The lower the LCOE is, the higher is the economic potential compared to other competitive energies.

$$\text{LCOE}=\frac{\text{OC}}{\text{CF}\times 8760}\times\text{CRF}+\text{OMC}+\text{FC} \quad \text{with CFR}\times\frac{\text{r}\times(1+\text{r})^{\text{r}}}{(1+\text{r})^{\text{r}}-1} \tag{2}$$

where OC is the overnight construction cost (or investment without accounting for interest payments during construction); OMC is the series of annualized operation and maintenance (O&M) costs; FC is the series of annualized fuel costs; CRF is the capital recovery factor; CF is the capacity factor; r is the discount rate and T is the economic life of the plant (Timilsina et al. 2011:11)

A review of the solar energy market and trends of conventional and renewable energy will be explored before the paper analyzes **market potential** covering supply and demand, pricing, major market players, and policy regulations. More specifically, the prices will cover both conventional and renewable energy prices. Market players cover the product efficiency and financial statement of solar energy related companies in East Asia. The viability of solar energy policy will be examined with ‘political viability indicators’ by the International Renewable Energy Agency (IRENA) in order to analyze policy potential in each country.

Table 3. Political viability indicators

Issued addressed	Indicators
Existence of stakeholder support	• Existence of related policy, programs, plans, strategies, laws and activities • Register of stakeholders involved and their official viewpoint • Policy origins: developed internally in response to local ambition (endogenous), or response to pressures from external bodies (exogenous)
Stability of stakeholder support	• Consistency of government targets • Longevity of financial political commitments • Existence of incentives for stakeholders to comply with policy
Influence of stakeholder groups	• Ownership concentration of key industries • Power and organization of the public
Credibility of the policy	• Results achieved/ anticipated according to the evaluation of other criteria
Political appropriateness and acceptability of new development	• Political system • Importance of (renewable) energy to public • Stage of the electoral cycle • Rationale for deploying renewable technologies-compatibility or conflicts with other policy priorities

Source: IRENA (2014:37)

The results of research were accepted to be presented at the International Conference on Concentrating Solar Power and Chemical Energy Systems in China (SolarPACES September 2014). Furthermore, also the Expo Solar PV Conference[2] in South Korea was visited in September 2014.

The term ‘East Asia’ in this paper indicates the countries People’s Republic of China, Republic of Korea, and Japan. The results of this thesis show that particularly China has a great potential of resources and technical capabilities, supported by a promotional policy framework.

1.3. Theoretical background - a review of solar energy technology

We can simply divide the solar energy technology into photovoltaic (PV) and concentrating solar power plants (CSP). First of all, let us look into the background of solar photovoltaic. In 1839, the French physicist Edmond Becquerel discovered the photoelectric effect which became the basis of the photovoltaic technology. In 1905, the process of the effect was explained by Albert Einstein. Darryl Chapin, Calvin Fuller and Gerald Pearson designed the silicon solar cell for powering satellite application in 1954. Elliot Berman modified PV to terrestrial applications in the early 1970s. The thin films technology was introduced in 1986 (IEA 2011a).

1. Photovoltaic is the technology that converts photons from solar radiation to electricity using semiconductor devices. Currently, wafer-based crystalline silicon (c-Si) and thin films are commercial PV technologies. There are single-crystalline silicon (sc-Si) and multi-crystalline silicon (mc-Si) used for the crystalline silicon technology. These two technologies account for approximately 85 percent of the market. The cell efficiencies – the percentages of

[2] International Solar Energy Expo and Conference International Photovoltaic Power Generation Expo Korea at KINTEX, South Korea Sept. 17th-19th Sept. 2014

electric productivity from solar radiation – show 14 % to 22 % for sc-Si and 12 % to 19 % for mc-Si (IEA 2011a).

Thin films technology deposits semi-conductors on thin layers. There are four categories of photovoltaic materials: amorphous silicon (a-Si) with efficiencies from 4 % to 8 %, multi-junction thin silicon films (a-Si/μc-Si) which consist of a-Si with other a-Si and micro-crystalline silicon (μc-Si) with efficiencies up to 10%, cadmium-telluride (CdTe) with efficiency of 11%, and copper-indium-(di) selenide (CIS) and copper-indium-gallium-(di) selenide (CIGS) showing from 7 to 12 % efficiency rates (IEA 2011a).

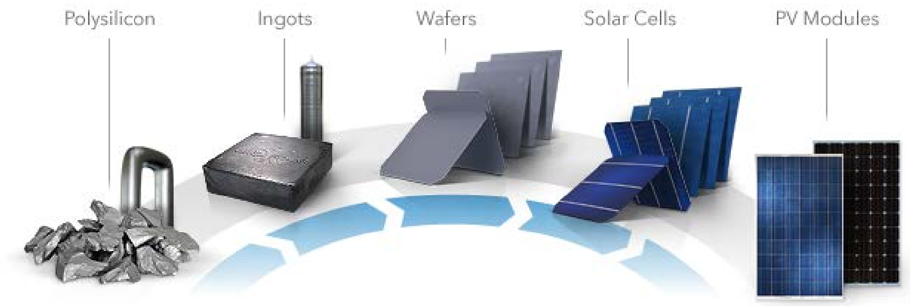
Table 4. The efficiency rate of solar energy technologies

Photovoltaic technology		Efficiency rates (%)
Crystalline silicon	sc-Si	14-22
	mc-Si	12-19
Thin film	a-Si	4-8
	a-Si/μc-Si	Up to 10
	CdTe	11
	CIS and CIGS	7-12

Source: IEA (2011a)

The solar PV modules are produced in the following five steps. Polysilicon is transformed into ingots, which are role-shaped blocks of polysilicon, the raw material for PV modules. In order to produce ingots, the silicon should be heated over 2,000 degrees. The wafers are sliced pieces from ingots and the size of a wafer is less than 200 microns thick. Solar cells are made from the wafers and the finished PV module consists of the solar cells.

Figure 2. The solar PV related products



Source: Yingli (2014a)

2. Concentrating Solar Power: There are mainly three types of concentrating solar power technologies: Solar tower, parabolic trough, and parabolic dishes. The solar towers (central receiver systems) consist of reflecting mirrors (heliostats) and central receivers on top of the tower. The heliostats reflect the sunlight towards the receiver. A heat-transfer fluid in the receiver can be used for steaming to generate electricity or for later use during nights and cloudy days.

A parabolic trough is composed of parallel rows of U-shaped reflectors in one dimension to capture the sun rays. The concentrators reflect the sun rays toward the receiver which is installed inside the concentrators. The collectors follow the lights east to west. The parabolic trough system is one of the most used concentrators for solar thermal electricity. The trough plants are installed in Spain and in the U.S.A. The parabolic trough dominates the CSP market representing about 95 percent of facilities in operation at the end of 2011 (REN 21, 2013).

Parabolic dishes (Dish Engine system) are the technology that receives solar rays reflected from mirrored dishes at a focal point. The whole equipment traces the sun with the dishes and the receiver together. Currently, most of parabolic dishes are used for independent electricity generators. (IEA 2011a; NREL 2012)

Figure 3. CSP Technologies (from left: solar tower, parabolic trough, and dish-stirling)

Source: WGA (2006:6)

Based on this introduction into the various solar energy technologies, and the theoretical background on how to analyze the solar energy potential, the following section thoroughly collects and discusses the data on solar energy in China, South Korea, and Japan. The analysis follows the previously introduced framework in the four dimensions of Resources, Technology, Economy, and Market.

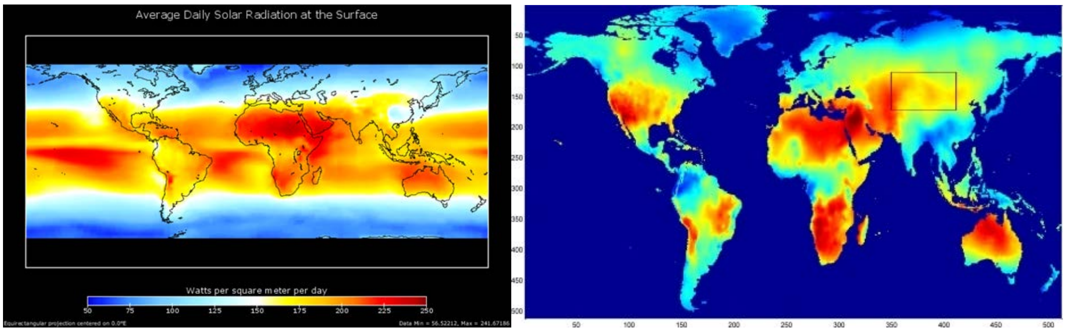
2. Empirical Analysis

2.1. Resources (Theoretical potential)

The basic element of any solar energy potential would be the theoretical potential that is the resource. It is important to scrutinize the resource in order to know the total potential quantity of the solar energy in each area. The theoretical potential of solar energy is the radiation measured on the surface of the earth per year (Hoogwijk, 2004). Other important reason to examine the resource potential is that it influences the cost of the solar collectors for a solar plant. In order to run a cost-effectively operation, the radiation records are needed. Therefore, the solar resource is the most essential and basic physical information for the analysis of the solar energy potential (WGA, 2006).

According to an estimation by Johannson et al., the theoretical solar energy potential in the world is about 3,900,000 exajoules a year, whereas wind energy has 6,000 exajoules and ocean energy has 7.400 exajoules potential (Johannson et al. 2004). When we look at the global solar radiation, East Asia (except north-western regions in China) shows relatively low solar energy potential in terms of average daily global solar radiation at the surface. The northwest and southwest China region receives the most solar radiation in East Asia. Middle East Asia and the Sahara desert area, Australia, and the South East of the U.S.A have comparatively high solar energy potential. The below map indicates areas of high solar radiations in red.

Figure 4. Map of global average daily solar radiation at the surface and mean monthly surface sunshine duration



Source: left: Wheeler (2008), right: Guo et al (2011:6)[3]

In this part, the solar energy potential will be analyzed by examining the quantity of solar radiation and sunshine duration. The radiation and sunshine time is collected by each country's meteorological organization and also available through scholarly articles. By studying the sub-criteria, we can refer to the potential area in each nation in terms of resources.

2.1.1. Solar radiation quantity

Solar radiation data on the earth's surface is used as an essential input and a fundamental parameter in the field of solar energy-based projects as well as others like climatology, hydrology, and architecture (Na et al. 2012). The solar radiation is a very crucial variable in order to design a solar energy conversion system (Wang and Zhang 2010). It is also one of the most predominant measurements in solar energy potential studies (Stritih et al. 2013). According to Hoogwijk, the total theoretical potential of sunlight is $176 \cdot 10^3$ petawatt per hour (PWh) y^{-1}, or $633 \cdot 10^3$ EJ y^{-1} that is approximately 1,500 times the current global energy use (Hoogwijk, 2004)[4].

In this section, the quantity of solar radiation for each nation is examined. The radiation analysis based on region would be referred to someone who develops solar power plant and installs solar PV. Firstly, existing analyzes that studied global focused solar radiation will be presented. Afterwards, studies that focus on particular provinces and cities in each nation will be explained.

The results of the solar radiation in China, South Korea, and Japan differ within the various papers due to diverse ways of measuring and modeling. The units are also different in each article. According to the national renewable energy laboratories (NREL), the total solar radiation per year amounts to 27,373,606,560 megawatt per hour (MWh) in China, 250,682,398.4 MWh in South Korea, and 809,152,633.5 MWh in Japan (Open EI, 2014). The estimated quantity of radiation in China is the second largest in the world in terms of solar

[3] Mean monthly surface sunshine duration in June over global land areas, excluding Antarctica.
[4] A Joule is a unit of energy while a Watt is a unit of power. In other words, a Joule is energy that has capability to do work whereas a Watt is a power that is energy during certain interval of time. 1 Watt = 1 Joule/sec.

radiation for whole nation, whereas South Korea's is the 109th, and Japan is the 67th. Of course, the result is highly dependent on the size of the country. However, when we calculate the average solar radiation per square meter, the ranking remains similar for each country.

Jo and Kang evaluated solar energy resources in East-North Asian areas. They collected actual surveys in Beijing and Hangzhou, and 26 predicted data through satellite modeling in China. 16 places' actual data in South Korea were surveyed and 17 regions are assessed in Japan. They estimated that China receives a yearly average solar radiation of 3.58 kilowatt hour (kWh)/m^2 per day. South Korea receives 3.59 kWh/m^2 per day, and Japan 3.70 kWh/m^2 per day (Jo and Kang 2006; 2008). According to Avlite company's research which collects data in 21 cities in China, 13 cities in South Korea and 80 cities in Japan, China has a yearly average radiation of 3.87 kWh m^2 /day, whereas South Korea has 3.33 kWh m^2 /day and Japan has 3.63 kWh m^2 /day (Avlite, 2014). The National Aeronautics and Space Administration (NASA) offers solar insolation quantity information based on latitude and longitude. The data was collected during a period of 22 years (July 1983 - June 2005) and gives a monthly and annual average (NASA 2008). As the author collected data from the same cities via Avlite's data, the values are 4.03 kWh/m^2/day in China, and 4.02 kWh/m^2/day in South Korea. In Japan, the 10 largest cities in Japan were chosen and the average value is 3.73 kWh/m^2/day. As mentioned before, the results vary due to selection of locations or the method of analysis.

Table 5. Comparison of solar radiation average quantity per day in China, South Korea and Japan. (Unit: kWh/m^2/day)

Jo and Kang			Avlite			NASA		
China	S.Korea	Japan	China	S.Korea	Japan	China	S.Korea	Japan
3.58	3.59	3.70	3.87	3.33	3.63	4.03	4.02	3.73

Sources: Jo and Kang (2006), Jo and Kang (2008), Avlite (2014), NASA (2008)

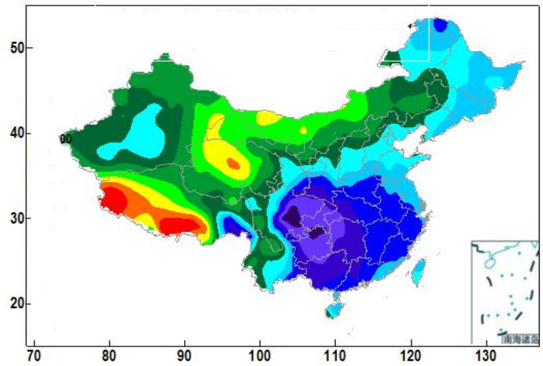
2.1.1.1. Solar radiation in China

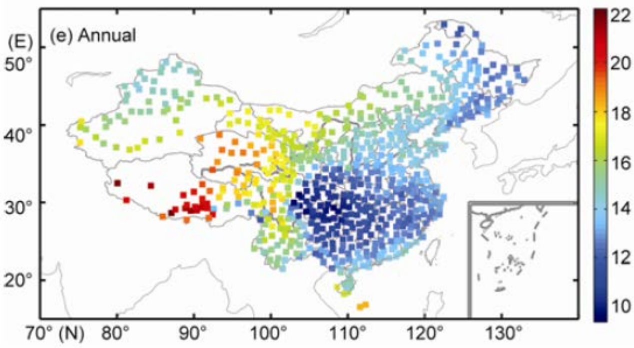
Tang et al. (2011) stress that there are limitations of analyzing solar radiation in China. First, even though 122 radiation stations are in China, only four radiation stations (Lhasa, Shiquanhe, Naqu, and Germu) are located on the Tibetan Plateau which covers about one-fourth of China. Their second argument is that the retrofit of obsolete instruments, the removal of stations, and the poor maintenance of the instruments cause difficulties of observing and producing a quality-consistent long-term dataset. Lastly, they mention that the radiation stations are equipped mostly in developed urban or suburban areas. Hence, the results from the stations cannot represent developing and less industrialized locations.

Overall, the annual mean daily solar radiation in China is 14.3 MJ m^2. The north and west of China receive more radiation than the south and east. 27.1 MJ m^2 of mean daily solar radiation is measured in the Tibetan Plateau during summer while the Sichuan Basin has that of 4.7 MJ m^2 in winter (Tang et al 2012). When we look at the below Figure, there is abundant solar radiation in Tibet and Qinghai province. On the other hand, Sichuan, Guizhou, and Heilongjiang have the lowest radiation in China. The red-colored regions present rich solar radiation, whereas the blue areas indicate low solar radiation.

Figure 5. China solar radiation yearly gross

China solar radiation yearly gross quantity 1978~2007 Daily solar radiation average 1961-2010 (Unit: MJ m^2)





Source: left – CMA wind and solar energy resources center (2011), right – Tang (2012: 10)

Meanwhile, the radiation results by cities are different from those presented in related papers. In Li et al.'s (2012) article, Zhengzhou, Henan and Shenyang, Liaoning have the most abundant solar radiation whereas Lanzhou, Gansu and Geermu, Qinghai are the cities which have less radiation among 17 cities in China. However, Geermu, Qinghai is presented as the city that receives most radiation while Guangzhou, Guangdong appears to be the least radiation-receiving city among 8 cities in China in Tang's paper (Tang et al. 2011). When we look at Lam et al.'s (2008) research, the value of global solar radiation is high in Golmud, Qinghai and is low in Yichang, Hubei among 6 cities in China. According to Jo and Kang's data, Lhasa, Beijing, Kunming, Yinchuan, and Hotan are the top 5 cities which have plentiful solar radiation among 28 cities in China, whereas Guiyang, Chengdu, Hangzhou, Yichang, Hailar, and Qiqihar receive less radiation (Jo and Kang, 2007).

Table 6. Annual average daily global radiation by cities in China (Unit: kWh/m^2/day)

Name of City	Name of province	Radiation	Name of City	Name of province	Radiation
Lhasa	Tibet	4.31	Hailar	Inner Mongolia	3.38
Beijing	-	4.03	Yichang	Hubei	3.34
Kunming	Yunnan	3.93	Hangzhou	Zhejiang	3.24
Yinchuan	Ningxia	3.91	Chengdu	Sichuan	2.93
Hotan	Xinjiang	3.85	Guiyang	Guizhou	2.89

Source: Jo and Kang (2007)

Zhao et al. (2011) studied the photovoltaic market in China and presented the solar radiation in China by province. According to their data, Tibet having 7,911 MJ m^2 has the highest solar energy potential in terms of resources in China. Tsinghai, Gansu, Xinjiang, and Inner Mongolia have 6,952, 6,459, 6,342, 6,195 MJ m^2 of solar radiation, respectively.

Table 7. Annual radiation by provinces in China

Province	Annual radiation		Annual radiation in the provincial capital (on tilted plane)		Tilted angle (degree)
	Max (MJ m^2)	Min (MJ m^2)	Amount (MJ m^2)	Potential resources [5](kWh m^2)	
Tibet	7,911	6,089	8,832	2,453	30
Tsinghai	6,952	6,143	7,064	1,962	40
Gansu	6,459	5,443	6,259	1,739	40
Xinjiang	6,342	5,305	6,101	1,695	45
Inner Mongolia	6,195	5,658	6,948	1,930	45
Beijing	5,620	5,620	6,294	1,748	42
Jiangsu	4,855	4,855	5,341	1,484	35
Guizhou	4,672	3,471	4,102	1,139	30
East of Sichuan	4,230	3,487	4,248	1,180	35
Hunan	4,213	4,213	4,639	1,287	30
South of Anhui	3,793	3,793	4,361	1,211	35

Source: Zhao et al (2011:2)

In order to analyze the resource potential of solar energy by region in China, Ming et al. (2013) divided the areas into four groups by abundance of solar radiation; most abundant (more than 1,750 kWh/m^2), very abundant (1,400-1,750 kWh/m^2), abundant (1,050-1,400 kWh/m^2), and normal (less than 1,050 kWh/m^2). 17.4 percent out of total area in China is in the category of the most abundant category. The provinces in the most abundant areas are Tibet, South Xinjiang, Qinghai, Gansu, and West Inner Mongolia. 42.7 percent of China belongs to very abundant category and 36.3 percent is the abundant area. Sichuan and Guizhou are categorized having normal radiation.

Table 8. Solar energy resource distribution by region in China

Category	Annual solar radiation (kWh/m^2)	Percent of total area (%)	Areas
Most abundant	≥1,750	17.4	Tibet, South Xinjiang, Qinghai, Gansu, West Inner Mongolia
Very abundant	1,400-1,750	42.7	North Xinjiang, Northeast China, East Inner Mongolia, Huabei, North Jiangsu, Huangtu Plateau, East Qinghai and Gansu, West Sichuan, Hengduan Mountain, Fujian, South Guangdong, Hainan
Abundant	1,050-1,400	36.3	Hill areas in Southeast, Hanshui river basin, West Guangxi
Normal	<1,050	3.6	Sichuan, Guizhou

Source: Ming et al. (2013:262)

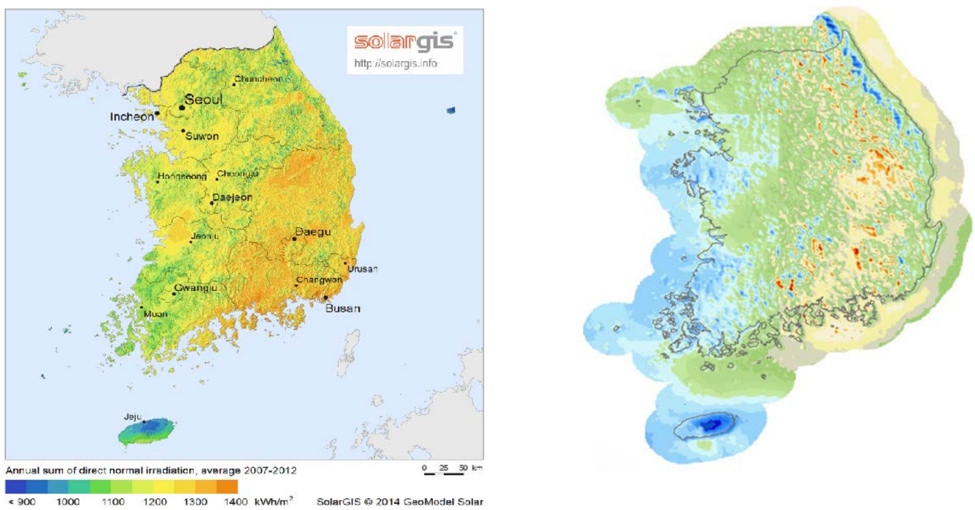
It is not easy to hierarchically order Chinese cities based on solar radiation due to the differences in articles and databases. However, the fact that the south-west region especially Tibet and Qinghai area has the most radiation is obvious. Therefore the area is regarded as the best potential place to install solar PV and CSP in China.

[5] Potential resource = Radiation amount/3.6 ($1Wh=1Js^{-1}\times3600s=3.6kJ$, thus 1kWh=3.6MJ)

2.1.1.2. Solar radiation in South Korea

In this section, the quantity of regional and seasonal solar radiation in South Korea will be examined. The orange-colored area on below left map and red-colored area on the right one present the areas of rich solar radiation, whereas the blue-colored regions have lower radiation. Looking at the yearly average direct radiation in South Korea, the south-east regions show more radiation while the radiation is less in the west-coast and on Jeju Island.

Figure 6. Yearly direct normal radiation in South Korea



Source: Left – SolarGIS (2011), Right – National Institute of Meteorological Research (NIMR, 2014)

Jo et al. (2012) analyzed solar radiation in South Korea by measuring cloud cover and hours of bright sunshine. In their paper, the city of Mok-po appeared to have the most solar radiation of 3.90 kWh/m^2/day among 16 cities in South Korea, whereas the capital Seoul showed minimum solar radiation of 3.26 kWh/m^2/day. The average solar radiation in South Korea is indicated as 3.62 kWh/m^2/day. Jeong (2012) surveyed the global insolation of the same 16 cities in South Korea. In this paper, Mok-po is shown to receive 3,344 kcal (3.89 kWh[6])/day, and Seoul had 2,780 kcal (3.23 kWh) /day of radiation. The Korean Meteorological Administration (KMA) investigated the solar radiation for a period of 20 years (1988 - 2007). According to the data, the annual average solar radiation on the surface in South Korea is 4.95kWh/m^2/day and annual direct solar radiation is 5.41 kWh/m^2/day (KMA 2008). Looking at the solar radiation by cities, Mok-po recorded the highest radiation in South Korea. These three sources tell us that the south-west region of South Korea, where the cities Mokpo, JinJu, and Gwangju are located, has plentiful solar radiation. On the other hand, the northeast and Jeju Island have relatively low solar radiation.

[6] 1kWh=859.85kcal. 1 Watt= 1 Joule/sec

Table 9. Annual daily solar radiation quantity by cities in South Korea

Jo et al (2012)			Jeong (2012)			KMA (2008)		
Name of cities	Name of province s	Radiation (kWh/m^2/ day)	Name of cities	Name of province s	Radiation (kcal/day)	Name of cities	Name of provinces	Annual radiation (MJ/ m^2)
Mokpo	Jeolla namdo	3.90	Mokpo	Jeolla namdo	3,344	Mokpo	Jeolla namdo	5,110.39
Jinju	Gyeong sangnam do	3.86	Jinju	Gyeong sangnam do	3,309	Jinju	Gyeong sangnam do	5,047.29
Seosan	Chung cheong namdo	3.74	Seosan	Chung cheong namdo	3,206	Heuksan-do	Jeollanam do	4,980.13
Busan	Busan	3.73	Gwangju	Gwangju	3,170	Gwangju	Gwangju	4,864.33
Gwangju	Jeolla namdo	3.70	Busan	Busan	3,161	Daejeon	Daejeon	4,820.29

Source: own compilation from Jo et al. (2012); Jeong (2012); KMA (2008)

Looking at the solar radiation by months and seasons in South Korea, the highest daily solar radiation showing 5.04 kWh/m^2/day was measured in May whereas the least measurement of 1.88 kWh/m^2/day was collected in December. The solar radiation data shows higher results in spring that is April, May, and June than in summer July, August, and September.

Table 10. National average annual daily radiation by months in South Korea (unit: kWh/m^2/day)

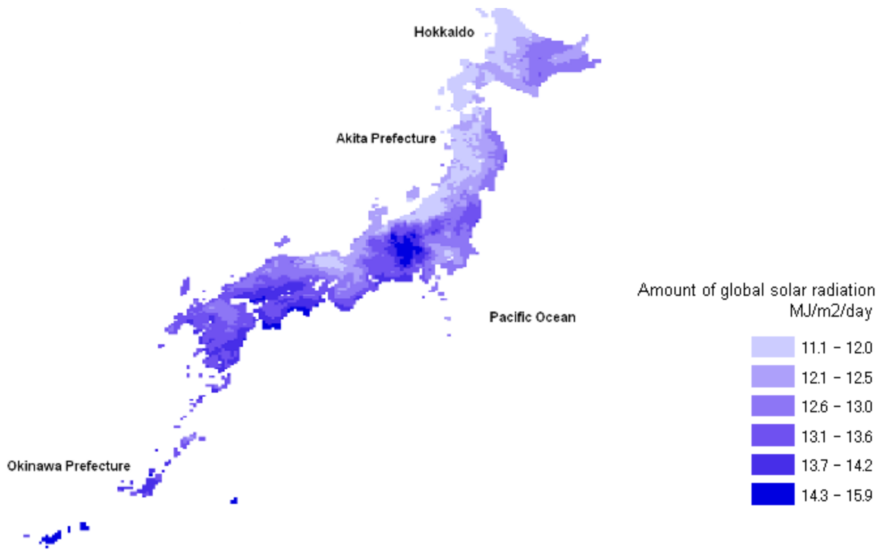
Month	January	February	March	April	May	June
Radiation	2.07	2.82	3.61	4.56	5.04	4.77
Month	July	August	September	October	November	December
Radiation	4.19	4.32	3.81	3.34	2.28	1.88

Source: Jo et al. (2011: 103)

2.1.1.3. Solar radiation in Japan

As we can see in the figure below, middle and south-west regions of Japan have much solar radiation potential. The northern area shows relatively low solar radiation. The darker the blue color appears in the map, the more solar radiation occurs in the region.

Figure 7. Solar Radiation map in Japan



Source: CleanBiz.Asia

Table 11 below shows the solar radiation records of 10 cities in Japan. According to the Japan Meteorological Administration (JMA), the values collected from 175 stations of solar radiation have been saved by month and year since 1961. For this thesis, the cities by the largest region over Japan were selected. According to JMA's data, Osaka measuring 14.06 MJ/m^2 per day presents the city receiving the most solar radiation. The solar radiation quantity of Hiroshima is followed by Kumamoto, Nagasaki, and Tokyo. There is a tool called 'NEDO (New Energy and Industrial Technology Development Organization) solar radiation database reading system to check the solar radiation in Japan. In the system, the location by prefecture and spot can be chosen. The results are based on an annual optimal degree of solar radiation. Hamamatsu presenting 4.38 kWh/m^2/day has the most solar radiation among 10 cities. Kobe and Kagoshima have 4.21 kWh/m^2/day solar radiation. Tokyo and Kyoto receive 3.74 kWh/m^2/day. Jo and Kang (2006) selected 17 spots by regions in Japan in order to assess solar radiation. According to the research, Naha in Okinawa representing 3.82 kWh/m^2/day recorded the most solar radiation in Japan. The values are estimated at 3.75 kWh/m^2/day in Osaka, 3,72 in Shizuoka, 3.54 in Tokyo and 3.63 in Fukuoka. The results of the radiation between NEDO, JMA and Jo and Kang's show different results. However, in general it can be confirmed that the south western areas have more solar radiation potential than the north eastern, as the above map also showed.

Table 11. Solar radiation by cities in Japan

JMA(2014)			NEDO (2013)			Jo and Kang (2006)		
Station name	Prefecture	Radiation (MJ/m^2/day)[7]	City	Prefecture	Radiation (kWh/m^2/day)	City	Prefecture	Radiation (kWh/m2/day)
Osaka	Osaka	14.06	Hamamatsu	Shizuoka	4.38	Naha	Okinawa	3.82
Hiroshima	Hiroshima	14.02	Kobe	Hyogo	4.21	Osaka	Osaka	3.75
Kumamoto	Kumamoto	14.00	Kagoshima	Kagoshima	4.21	Shizuoka	Shizuoka	3.72
Nagasaki	Nagasaki	13.60	Hiroshima	Hiroshima	4.17	Tokyo	Tokyo	3.64
Tokyo	Tokyo	13.48	Kumamoto	Kumamoto	4.11	Fukuoka	Fukuoka	3.63
Shimonoseki	Yamaguchi	13.34	Osaka	Osaka	3.91	Kagoshima	Kagoshima	3.61
Fukuoka	Fukuoka	12.78	Sendai	Miyagi	3.86	Nagoya	Aichi	3.56
Fukushima	Fukushima	12.70	Sapporo	Hokkaido	3.82	Nagano	Nagano	3.54
Aomori	Aomori	12.00	Tokyo	Tokyo	3.74	Hiroshima	Hiroshima	3.49
Sapporo	Hokkaido	10.88	Kyoto	Kyoto	3.74	Sapporo	Sapporo	3.24

Source: own compilation from NEDO (2013); JMA (2014); Jo and Kang (2006)

Concluding the study of solar radiation in China, South Korea, and Japan, the potential of solar radiation mostly exists in the southern parts of each nation. Due to different measurement methods, the results of solar radiation vary, but give enough clarity to choose those regions that are optimal for CSP and solar PV installation.

2.1.2. Time of availability (Sunshine duration)

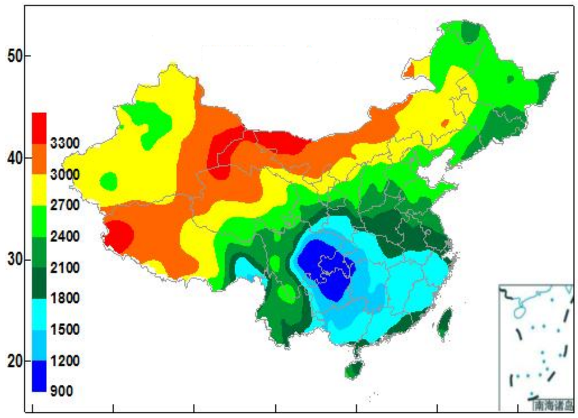
In this section, the sunshine duration which is closely related to the solar radiation will be examined (Matuszko, 2013; Akpabio, 2003). Not only the direct normal radiation but also the time of availability is a crucial criterion for planning a solar energy related system (Kreycik, 2010; KMA 2008). Clear days are essential for planning any solar equipment (Jo and Kang, 2006). The clearance was therefore used as a criterion for measuring the solar energy potential (Arvizu, 2011; Stritih, 2013). The definition of the sunshine duration is the sum of those periods when the solar direct irradiance reaches or exceeds 120 w/m^2, taking the hour as unit (Qian et al. 2012). By analyzing the time of solar availability, we are therefore able to enlarge the analysis of the solar energy potential in each nation.

2.1.2.1. Sunshine duration in China

The sunshine duration in China presents very similar results as the solar radiation distribution. The highest sunshine duration occurs in the southwest and northwest areas of China. The west part of Tibet, and northeast Gansu and Inner Mongolia have more than 3,300 sunshine duration hours per year. On the other hand, Chongqing and Chengdu have the lowest sunshine duration hour presenting less than 1,200 hours.

[7] Global solar radiation for 5 years average 2009-2013

Figure 8. China Yearly average sunshine duration 1978-2007 (Unit: Hours/ year)



Source: CMA wind and solar energy resources center (2011)

According to five-year average sunshine duration data from the National Bureau of Statistics of China (NBSC), Lhasa recorded the most sunshine showing 3,123.28 hours per year in China. 2,875.82, 2,740.28, and 2,596.72 hours per year were measured in Urumqi, Yinchuan, and Xining, respectively. Qian et al. (2012) collected data from Chinese Climatological Data at 756 meteorological stations from 1971 to 2000. Shiquanhe station located in Tibet indicated the longest sunshine duration, 3,553.9 hours per year. 3,127.9, 3,030.7, and 2,990.1 sunshine hours per year were measured in Delingha, Jiuquan, and Lasa, respectively. The National Oceanic and Atmospheric Administration (NOAA) recorded sunshine duration hours from 1961 to 1990 by regions. 3,103 hours per year were noted in Ruoqian in Xinjiang, 3,056 were shown in Jiuquan in Gansu, and 2,989 were indicated in Altay in Xinjiang. To conclude this part, Tibet, Xinjiang, Qinghai, Gansu, Ningxia, and Inner Mongolia present the most sunshine duration in China.

Table 12. Sunshine durations of the investigated observatories or stations in China

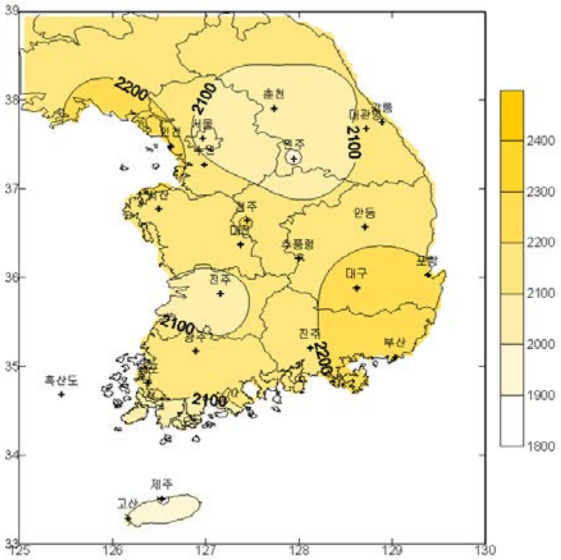
NBSC (2009-2013)			Qian et al. (2012)			NOAA (1998)		
City	Province	Average hours/ year (2008-2012)	Station	Province	Average hours/ year	Location	Province	Average hours/ year (1961-1990)
Lhasa	Tibet	3,123.28	Shiquanhe	Tibet	3,553.9	Ruoqiang	Xinjiang	3,103
Urumqi	Xinjiang	2,875.82	Delingha	Qinghai	3,127.9	Jiuquan	Gansu	3,056
Yinchuan	Ningxia	2,740.28	Jiuquan	Gansu	3,030.7	Altay	Xinjiang	2,989
Xining	Qinghai	2,596.72	Lasa	Tibet	2,990.1	Yinchuan	Ningxia	2,977
Hohhot	Inner mongolia	2,581.74	Wulan-haote	Inner Mongolia	2,875.2	Qiqihar	Heilong-jiang	2,848

Source: own compilation from NBSC (2009-2013); Qian et al. (2012); NOAA (1988)

2.1.2.2. Sunshine duration in South Korea

In South Korea, the south-east region and the city, Incheon area present relatively much sunshine duration hours. The central area of the Korean peninsula, such as Chuncheon and Wonju, as well as the southern region like Jeonju and Jeju Island recorded comparatively lower sunshine duration hours (KMA, 2008).

Figure 9. Annual average sunshine duration in South Korea (Unit: hours)



Source: KMA (2008: 59)

Jo et al. (2012) surveyed the daily average the duration of sunshine in 16 stations in South Korea between 1982 and 2010. The survey showed that Yeongju located in Gyeongsangbuk-do recorded the longest duration of sunshine stating 6.6 sunshine hours per day. Busan (6.3 hours per day), Daegu (6.1), Cheongju (6.0), and Pohang (6.0) have the longest duration of sunshine among South Korean cities. The national average is 5.8 hours. Looking into the sunshine duration by month, May indicating 7.1 hours per day is the month with the longest sunshine duration, whereas December (5.1) turns out to be the second shortest month.

KMA observed the yearly sunshine duration for 20 years (1988-2007) in 22 stations. The average annual sunshine duration in South Korea was 2,122.5 hours. Incheon had the longest sunshine duration recording 2,305.6 hours per year. When we examine the sunshine duration by month, May (215 hours per month), April (212.9), and October (198.7) presented the highest figures (KMA, 2008).

According to the data from the NOAA, the city of Yeosu recorded the most sunshine duration stating 2,429.7 hours per year. The cities Busan, Incheon, and Chupungnyong indicated 2,318.3, 2,315.3, and 2,250.6 hours per year, respectively (NOAA, 2008).

Table 13. Sunshine duration by city in South Korea

Jo et al (2012)		KMA (2008)		NOAA (1998)	
Name of city	Hours of duration of sunshine per day	Name of city	Hours of duration of sunshine per year (day)	Name of city	Hours of duration of sunshine per year
Yeongju	6.6	Incheon	2,305.6 (6.32)	Yeosu	2,429.7
Busan	6.3	Busan	2,291.7 (6.58)	Busan	2,318.3
Daegu	6.1	Daegu	2,245.5 (6.15)	Incheon	2,315.3
Cheongju	6.0	Cheongju	2,212.1 (6.06)	Chupungnyong	2,250.6
Pohang	6.0	Pohang	2,206.1 (6.04)	Pohang	2,197.8

Source: own compilation from Jo et al (2012); KMA (2008); NOAA (1998)

2.1.2.3. Sunshine duration in Japan

The data of sunshine duration from JMA in Japan are widely used. The Statistics Bureau in Japan also uses the data from JMA. In this chapter, the regions and the order of cities are the same as for the solar radiation examined above, which makes comparison easy. The sunshine duration data has been collected during the last 5 years since 2009. Like the solar radiation results above, the city Osaka has the longest sunshine duration in Japan, with 2,299.5 hours per year in 2013. Hiroshima (2,045.02 hours), Tokyo (1,996.10) and Kumamoto (1,963.02) follow. In general, south-west regions in Japan have more sunshine duration than north-east area (JMA, 2014).

Table 14. Sunshine duration by city in Japan for 5 years (2009-2014)

Name of city	2009	2010	2011	2012	2013	Average hours of duration of sunshine per year[8]
Osaka	2,000.6	2,031.9	2,462.6	2,058.2	2,299.5	**2,170.56**
Hiroshima	1,996.1	2,049.1	1,968.9	1,962.2	2,248.8	**2,045.02**
Kumamoto	1,985.3	1,886.1	1,886.2	1,860.6	2,196.9	**1,963.02**
Nagasaki	1,900.2	1,755.5	1,726.0	1,711.1	2,018.1	**1,822.18**
Tokyo	1,783.3	1,987.0	2,056.2	2,022.9	2,131.1	**1,996.10**
Shimonoseki	1,828.6	1,792.0	1,710.0	1,789.5	2,019.6	**1,827.94**
Fukuoka	1,807.0	1,833.1	1,819.9	1,799.0	2,058.5	**1,863.50**
Fukushima	1,689.4	1,737.3	1,825.3	1,751.4	1,844.3	**1,769.54**
Aomori	1,563.7	1,465.0	1,541.9	1,669.1	1,515.5	**1,551.04**
Sapporo	1,604.4	1,526.9	1,753.6	1,819.6	1,647.9	**1,670.48**

Sources: JMA (2014); Japan statistical yearbook (2014)

2.2. Technical potential

The technical potential relies on the land use, technical limitation, and the solar irradiation (Hoogwijk and Graus, 2008; Kreycik et al. 2010). Lopez et al. (2012) consider technical potential as system performance, topographic limitations, environmental and land-use constraints. Arvizu et al (2011) discuss the proper methodology for evaluating the technical potential of solar energy, taking into account the available solar irradiance, land use exclusion factors and the future development of technology improvements.

The technical potential of solar energy has already been explored by many scholars. Hoogwijk and Graus (2008) and Arvizu et al (2011) estimated the region-specific technical potential of solar energy on a global level. According to Johannson et al, the technical potential of global solar energy would be more than 1,600 Exajoules per year (Johannson et al. 2004). Lopez (2012) assessed the solar energy technical potential in urban and rural in the U.S.A. Stritih et al. (2013) explored the solar energy technical potential in Slovenian hospitals and houses in Turkey.

[8] 5-years average between 2009 and 2013.

In this section, we will examine the technical potential of specific areas in China, South Korea, and Japan, after explaining the equation and assumptions.

As mentioned in the introduction, the technical potential of solar energy can be calculated by the following equation and assumptions (Farooq and Kumar, 2013; Hoogwijk, 2004; Defaix et al. 2012). The technical potential in each country will be calculated with the formula and assumptions below:

$$E = A \times Gpoa \times \eta \times PR \quad (1)$$

Where, E is the annual electricity production (kWh/yr), A is the usable roof or facade surface (km²), G_{POA} the average yearly irradiation in the tilted horizontal or vertical plane of array (POA) per square meter (kWh/m²/yr), η the average module efficiency (%) and PR is the system performance ratio (Defaix et al. 2012: 2646).

Assumptions:

- Crystalline silicon technology is chosen because of its higher efficiency and higher market share (Farooq and Kumar, 2013; Teske and Masson, 2011; Makrides, 2010)
- The average efficiency of module is 15%. In this study, we assume efficiency of PV system as 15 % (Farooq and Kumar, 2013)
- The suitable area is completely covered by PV modules (Hoogwijk, 2004)
- The system performance ratio of the best system is between 0.66 and 0.85. In this paper, we assume the performance ratio is 80 % (Hoogwijk, 2004; Defaix et al. 2012)
- The area of building sites, suitable for installing PV modules, lies in between 9.2 % to 35.8 % in South Korea (= 16.2 % on average). Due to lack of data for China, we therefore calculate with 15 % of available rooftop area in Chinese provinces.

2.2.1. Technical potential by provinces' rooftop space in China

The table 15 below presents the technical potential with respect to certain provinces' rooftop space in China. Due to the large area, Xinjiang province has a calculated potential of 115.38 TWh/day and therefore shows the greatest potential in China even though the province's solar radiation does not present the highest result. Tibet (93.26 TWh/day) receiving the highest radiation in China marks the second-largest technical potential followed by Inner Mongolia (69.67 TWh/day), Heilongjiang (27.54 TWh/day), and Yunnan province (27.11 TWh/day). However, like mentioned above the geography and topology in each province should be added in a more detailed, exact technological potential study.

Table 15. Area of provinces and technical potential of rooftop in China

Name of province	Annual-average daily global radiation ($kWh/m^2/day$)	Area: 10,000 Hectares[9]	Technical potential of rooftop (GWh/day)	Name of province	Annual-average daily global radiation ($kWh/m^2/day$)	Area: 10,000 Hectares	Technical potential of rooftop (GWh/day)
Xinjiang	3.85	16,649.0	115,377.57	Guangdong	3.42	1,798.1	110.69
Tibet	4.31	12,020.7	93,256.59	Shandong	3.83	1,571.3	108.33
Inner Mongolia	3.38	11,451.2	69,669.10	Shanxi	3.81	1,567.1	107.47
Heilongjiang	3.38	4,526.5	27,539.23	Liaoning	3.65	1,480.6	97.28
Yunnan	3.93	3,831.9	27,106.86	Guizhou	2.89	1,761.5	91.63
Gansu	3.63	4,040.9	264.03	Fujian	3.64	1,240.2	81.26
Sichuan	2.93	4,840.6	255.29	Zhejiang	3.24	1,054.0	61.47
Guanxi	3.47	2,375.6	148.38	Ningxia	3.91	519.5	36.56
Shaanxi	3.43	2,047.9	126.44	Beijing	4.03	164.1	11.90
Jilin	3.38	1,911.2	116.28	Shanghai	3.52	82.4	5.22
Hubei	3.34	1,858.9	111.76				

Source: own calculation, based on Jo and Kang (2007) and China Statistical yearbook (2013)

2.2.2. Technical potential by cities' building sites in South Korea

The five main cities in South Korea are chosen for comparing the technical potential area. South-east areas such as Daegu and Busan appear to have the best technical potential in terms of total area. Daegu presents a technical potential of 391.09 GWh/day with respect to the city area. Busan, Seoul, Daejeon, and Gwangju are assessed with 340.11, 241.96, 244.81, and 222.64 GWh/day, respectively. If we look at the technical potential with respect to building sites, Seoul (86.53 GWh/day) naturally appears to have the highest technical potential in South Korea. Busan shows a technical potential of 46.17 GWh/day and Daegu shows 35.82 GWh/day with respect to building sites.

Table 16. Area of cities and technical potential in South Korea

Name of the city	Annual-average daily global radiation ($kWh/m^2/day$)	Area (km^2)	Technical potential of the city area (GWh/day)	Area of building site (km^2)	Technical potential of building site (GWh/day)
Daegu	3.68	885.61	**391.09**	81.11	**35.82**
Busan	3.73	759.86	**340.11**	103.15	**46.17**
Seoul	3.33	605.50	**241.96**	216.54	**86.53**
Daejeon	3.78	539.83	**244.87**	62.57	**28.38**
Gwangju	3.70	501.44	**222.64**	55.82	**24.78**

Source: own calculation, based on Jo et al. (2012); Ministry of Land, Transport, and Martime (2012); Korea National Statistical Office (2013)

[9] 1 Hectare (ha)=0.01km^2

2.2.3. Technical potential by cities' buildings in Japan

In this section, we will examine the technical potential in Japan by looking at the technical potential of the total area in the city as well as the usable land for buildings – which was divided into buildings for dwellings, and buildings for non-dwellings. For calculating the results, data provided by NEDO (2013) for solar radiation and by Japan Statistical yearbook (2014) for the area are used. The results are proportional to the size of the area. Kagoshima, which is the largest of the chosen cities, has the highest technical potential in Japan with 2,411.82 GWh/day. Hiroshima having 2,093.67 GWh/day shows the second-largest technical potential, and Kumamoto presenting 1,735.57 GWh/day ranks third.

When we look at the technical potential of buildings for dwellings, Tokyo has the highest potential in Japan. It has a technical potential of 187.15 GWh/day. This is also proportional to area. The building area for dwellings in Tokyo is the largest among the assessed cities. The technical potential of buildings for dwelling of Osaka (147.33 GWh/day) and Kagoshima (128.83 GWh/day) follow Tokyo's.

The technical potential of buildings for non-dwellings is also proportional to the area. Osaka (91.49 GWh/day) has the highest technical potential in terms of building for non-dwellings. Tokyo (68.67 GWh/day) is the second and Hiroshima (63.05 GWh/day) is the third city in the ranking of technical potential with respect to non-dwelling buildings.

Table 17. Technical potential of city, building for dwellings and non-dwellings in Japan

City	Prefecture	Radiation ($kWh/m^2/day$)	Technical potential of total city (GWh/day)	Technical potential of building for dwellings (GWh/day)	Technical potential of building for non-dwellings (GWh/day)
Kagoshima	Kagoshima	4.21	2,411.82	128.83	53.05
Hiroshima	Hiroshima	4.17	2,093.67	114.59	63.05
Kumamoto	Kumamoto	4.11	1,735.57	109.49	48.83
Osaka	Osaka	3.91	414.77	147.33	91.49
Tokyo	Tokyo	3.74	466.30	187.15	68.67
Kyoto	Kyoto	3.74	694.74	65.97	31.86

Source: own calculation, based on NEDO (2013) and Japan Statistical Yearbook (2014)

Concluding this section, the technical potential of solar energy is directly proportional to the area. The studies in this section depend on data available for each country. We examined the technical potential of provinces in China, that of cities in South Korea, and that of buildings for dwellings and non-dwellings in Japan. To calculate more precise results, further area-specific data in more detail would be needed.

2.3. Economic Potential

The economic potential of solar energy is the technical potential at cost levels considered (Hoogwijk and Graus, 2008:6; Verbruggen et al. 2009). In other words, we can examine the economic potential by studying competitive energy sources (Nhan and Ha-duong, 2008). Krewitt et al. (2008) add that the framing conditions of the economic potential will be especially important if conventional energy and renewable energy technology meet at break-even. The economic potential also accounts for cost-competitiveness and technology cost related information and other economic indicators including ancillary effects (Kreycik et al. 2010). The definition of economic potential can vary because of different cost-benefit perspectives (UNDP, 2000). The economic potential is also defined by the United Nation Development Programme (UNDP, 2000) as an organizational measure for maintenance, sensitive operations and control, and timely repairs. The potential can be explored from a business (or project) perspective, from a macroeconomic perspective, or from a societal (welfare based) perspective. At business level, an individual investor is able to calculate engineering and economic life-cycle costs, using a financial perspective. More comprehensive accounting and financial costs including required policies should be considered for calculating a macroeconomic potential level (UNDP, 2000).

Hoogwijk (2004) estimated the global economic potential of PV electricity using the cost of PV electricity with Operation and Maintenance (O&M) costs and Balance of System (BOS) costs. Nahn and Ha-duong (2008) assessed the economical potential of renewable energy in Vietnam by estimating the energy resources such as Hydro-, geothermal-, wind- and other powers. Fthenakis et al. (2009) studied the technical, geographical, and economic feasibility for solar energy in the U.S.A by considering policies and other energy resources.

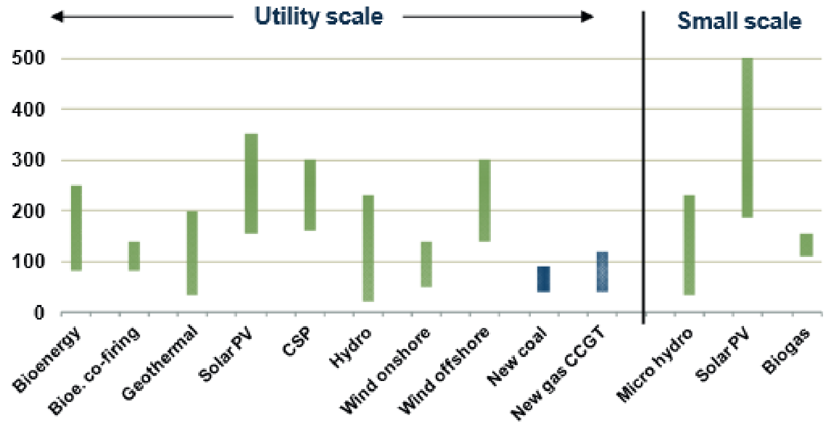
2.3.1. Levelized cost of electricity (LCOE)

The levelized cost is the traditional calculation method comparing the life-cycle cost of generating electricity with other technologies and is widely used (IEA and OCED 2010; Cambell 2008; Jeong 2013). The method reflects all investment and operational costs over the economic lifetime including fuel consumption and substitute of the machineries. In other words, the net present value of revenues from the plant's production and the net present value of the costs of output can be seen and compared by using LCOE (Baker et al. 2013). The LCOE normally covers primary investment costs, the cost of capital, the irradiance level and the performance ratio in an occasion of PV plants (IEA, 2011a). It also takes into account location, orientation, financing, and policies (Ardani and Margolis 2011; Kost et al. 2013).

The shortcomings of LCOE are also mentioned. The LCOE value varies given different assumptions, such as the economic lifecycle, capacity factors and discount rates (Timilsina et al 2011; Fadel et al. 2012). Larsson et al. (2013) point out that consumer perspective and external costs such as impact on society should be further considered in the LCOE value when using the results for planning purposes. What is more, the LCOE is a valid method for dispatchable electricity generating sources like nuclear, coal and liquefied natural gas (LNG), but less suitable for intermittent, non-dispatchable electricity such as from solar and wind power. The reason is, that due to environmental restrictions like sunshine duration, geographical location, degree, and rainfall, it is hard to calculate the cost of the solar energy electricity generation. However, the costs of conventional electricity-generating systems can be more easily calculated as the electricity can be generated when needed.

Looking at figure 10 below, the LCOE of solar energy is still higher than that of other energy sources, even among renewables. The LCOE of small-scale use of solar PV is also calculated as the highest.

Figure 10. Levelized costs of power generation (USD per MWh)



Source: IEA (2012b: 168)

Kost et al. (2013) estimated the LCOE of photovoltaics, wind power and biomass power plants in Germany. Fadel et al. (2012) assessed the LCOE per energy source in order to estimate the economic potential of renewable energies in the Middle East and North African (MENA) region. Ouyang and Lin (2014) studied the LCOE of renewable energies in China in order to prove that higher government support is needed. According to Timilsina et al., the LCOE of a power plant is estimated as follows:

$$\mathrm{LCOE}=\frac{\mathrm{OC}}{\mathrm{CF}\times 8760}\times \mathrm{CRF}+\mathrm{OMC}+\mathrm{FC}\quad \text{with CFR}\times\frac{\mathrm{r}\times(1+\mathrm{r})^{\mathrm{r}}}{(1+\mathrm{r})^{\mathrm{r}}-1} \tag{2}$$

where OC is the overnight construction cost (or investment without accounting for interest payments during construction); OMC is the series of annualized operation and maintenance (O&M) costs; FC is the series of annualized fuel costs; CRF is the capital recovery factor; CF is the capacity factor; r is the discount rate and T is the economic life of the plant (Timilsina et al. 2011:11).

In this part, we will examine the LCOE of conventional energy and solar energy in China, South Korea, and Japan to compare the costs. The LCOE data are mainly from the source of IEA and Organization for Economic Co-operation and Development (OECD). The calculation of the LCOE by IEA and OECD (2010: 59) considers below limitations.

1. Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).

2. Investment costs include overnight costs as well as the implied interest during construction.

3. In cases where two numbers are listed under O&M costs, numbers reflect 5% and 10% discount rates. The numbers differ due to country-specific cost allocation schedules.

2.3.1.1. The LCOE of solar PV in China

Comparing the LCOE of conventional energy such as nuclear, coal, and gas with solar energy, the cost of solar energy is much higher than the others in China at the moment. The cost of coal technology, which is most widely used in China, is the lowest in terms of LCOE. If we assume 10 percent discount rate, approximately 33.26 to 34.43 US dollars are necessary to generate coal-fired electricity. Gas-fired and nuclear electricity followed on rank two and three in terms of costs. The LCOE of gas is between 39.01 and 39.91 US dollars and that of nuclear energy lies between 44.0 and 54.61 US dollars. However, the LCOE of solar PV presenting 186.54-282.92 USD is approximately five times more expensive than other conventional energies (IEA and OECD, 2010).

Table 18. Traditional energy plants: Levelized costs of electricity in US dollars per MWh in China

Technology		Net capa-city	ECE[10]	Over-night costs	Investment costs		Decommissioning costs		Fuel Cycle costs	Carbon costs	O&M costs	**LCOE**	
					5%	10%	5%	10%				5%	10%
		MWe	%	USD/kWe	USD/kWe		USD/kWe		USD/MWh	USD/MWh	USD/MWh	USD/MWh	
Nuclear	CPR[11]-1000	1,000	-	1,763	1,946	2,145	0.08	0.01	9.33	-	7.10	**29.99**	**44.00**
	CPR-1000	1,000	-	1,748	1,931	2,128	0.08	0.01	9.33	-	7.04	**29.82**	**43.72**
	AP-1000	1,250	-	2,302	2,542	2,802	0.10	0.01	9.33	-	9.28	**36.31**	**54.61**
Coal-fired	Black USC[12] PCC	932	46	656	689	723	0.03	0.01	23.06	0.00	1.64	**29.99**	**34.17**
	Black SC[13]	1,119	46	602	632	663	0.03	0.01	23.06	0.00	1.51	**29.42**	**33.26**
	Black SC	559	46	672	705	741	0.03	0.01	23.06	0.00	1.68	**30.16**	**34.43**
Gas-fired	CCGT[14]	1,358	58	538	565	593	0.04	0.01	28.14	0.00	2.81	**35.81**	**39.01**
	CCGT	1,358	58	583	612	642	0.05	0.01	28.14	0.00	3.04	**36.44**	**39.91**

Source: IEA and OECD (2010: 59-61)

Table 19. Solar PV power plants: Levelized costs of electricity in US dollars per MWh in China

Tech-nology	Net capa-city	Load factor	Over-night costs	Investment costs		Decommissioning costs		Fuel Cycle costs	O&M costs	**LCOE**	
				5%	10%	5%	10%			5%	10%
	MWe	%	USD/kWe	USD/kWe		USD/kWe		USD/MWh	USD/MWh	USD/MWh	
Solar PV	20	21	2,878	2,949	3,019	-3.08	-1.47	0.00	15.65	**122.86**	**186.54**
Solar PV	10	18	3,742	3,834	3,924	-5.76	-2.22	0.00	23.87	**186.33**	**282.92**
Solar PV	10	21	2,921	2,921	2,993	-3.85	-1.49	0.00	15.88	**124.70**	**189.34**
Solar PV	10	18	3,598	3,598	3,598	-5.54	-2.14	0.00	22.82	**179.16**	**272.04**

Source: IEA and OECD (2010: 62)

If we compare the LCOE of solar energy with other renewable energies, the cost of solar PV is still higher than the others in China. The LCOE of onshore wind lies in between 72.1 and 125.80 US dollars per megawatt hour, with 10 percent discount rate. The large hydro technology is the most economically attractive source of renewable energy in China. The costs of generating electricity through hydro power can be even cheaper than the costs of other

[10] Electrical Conversion Efficiency
[11] Chinese PWR(Nuclear reactor)
[12] Ultra-Supercritical Technology
[13] Supercritical
[14] Combined-cycle gas turbine

conventional energies depending on the system. The LCOE of large hydro power plants are between 23.28-51.50 US dollars (IEA and OECD, 2010).

Table 20. Renewable power plants: Levelized costs of electricity in US dollars per MWh in China

Tech-nology	Net capa-city	Load factor	Over-night costs	Investment costs		Decommissioning costs		Fuel Cycle costs	O&M costs	LCOE	
				5%	10%	5%	10%			5%	10%
	MWe	%	USD/kWe	USD/kWe		USD/kWe		USD/MWh	USD/MWh	USD/MWh	
Onshore wind	200	27	1,223	1,253	1,283	-1.26	-0.48	0.00	15.51	**50.95**	**72.01**
Onshore wind	50	27	1,541	1,579	1,616	-1.58	-0.61	0.00	19.54	**64.18**	**90.70**
Onshore wind	35	22	1,627	1,667	1,707	-2.05	-0.79	0.00	25.33	**83.19**	**117.55**
Onshore wind	30	20	1,583	1,622	1,660	-2.19	-0.85	0.00	27.11	**89.02**	**125.80**
Large Hydro	18,134	53	1,583	1,792	2,027	0.014	0.005	0.00	9.85	**29.09**	**51.50**
Large Hydro	6,277	34	757	857	969	0.010	0.000	0.00	2.54	**16.87**	**33.57**
Large Hydro	4,783	57	896	1,014	1,147	0.007	0.0003	0.00	1.37	**11.49**	**23.28**

Source: IEA and OECD (2010: 62)

The LCOE of solar PV is currently not competitive compared to wind power and biomass in China. According to the calculation by Ouyang and Lin (2014), the costs of solar PV are at least 174.17 US dollars at maximum 288.95 USD with 10 percent discount rate. The LCOE of solar PV in Jialonggou plant, Tibet, where the theoretical and technical potential are the highest all over China, is assessed with the highest cost. The LCOEs of wind power in China presents between 102.74 USD and 132.76 USD while those of biomass show between 105.63 USD and 114.46 USD (Ouyang and Lin, 2014).

Table 21. The LCOE of solar PV, Wind powers, and biomass in China (Unit: USD/MWh)[15]

Solar PV				Wind power (onshore)				Biomass		
Plant name	Location	The LCOE		Plant name	Location	The LCOE		Plant name	The LCOE	
		5 %	10%			5 %	10%		5 %	10%
Gonghe	Qinghai	131.31	174.17	Laizhou	Shandong	100.17	132.76	Houde	100.65	112.85
Maigaiti	Xinjiang	134.68	181.88	Hala Haixiang	Heilong-jiang	88.61	117.02	Dangyang	104.02	114.46
Wuqia	Xinjiang	143.99	194.56	Ningdong	Ningxia	89.86	118.47	Hailun	104.50	114.46
Weiwu	Gansu	154.91	203.87	Turpan	Xinjiang	86.68	113.81	Baoquanling	93.91	105.63
Tianhe Yangguang	Qianghai	187.49	257.64	Azuoqi	Inner Mongolia	69.03	102.74	Houqiu	98.08	114.29
Jialonggou	Tibet	214.62	288.95	Qiaowan	Gansu	79.78	109.16			

Source: Ouyang and Lin (2014: 67-69)

2.3.1.2. The LCOE of solar PV in South Korea

The LCOE of nuclear energy, stating between 42.09 US dollars and 48.38 USD with 10 percent discount rate, is the lowest in South Korea. Comparing to the conventional energies' LCOE of China, the LCOE of South Korea is relatively higher. The costs of generating

[15] The cost was calculated from Chinese yuan to US dollars with currency rates at 1 US dollars = 6.23 Chinese yuan

electricity by using Coal lie in between 71.12 and 74.25 USD which is about twice as much as in China. Gas-fired electricity generation in South Korea, with an LCOE between 94.70 and 93.63 USD, is more than twice as expensive as in China (IEA and OECD, 2010).

Table 22. Traditional energy plants: Levelized costs of electricity in US dollars per MWh in South Korea

Technology		Net capa-city	ECE	Over-night costs	Investment costs		Decommissioning costs		Fuel Cycle costs	Carbon costs	O&M costs	LCOE	
					5%	10%	5%	10%				5%	10%
		MWe	%	USD/kWe	USD/kWe		USD/kWe		USD/MWh	USD/MWh	USD/MWh	USD/MWh	
Nuclear	OPR-1000[16]	954	-	1,876	2,098	2,340	0.09	0.01	7.90	-	10.42	**32.93**	**48.38**
	APR-1400[17]	1,343	-	1,556	1,751	1,964	0.07	0.01	7.90	-	8.95	**29.05**	**42.09**
Coal-fired	Black PCC	767	41	895	978	1,065	0.04	0.01	31.53	24.04	4.25	**68.41**	**74.25**
	Black PCC	961	42	807	881	960	0.03	0.01	30.78	23.50	3.84	**65.86**	**71.12**
Gas-fired	LNG CCGT	495	57	643	678	712	0.05	0.02	69.79	10.42	4.79	**90.82**	**94.70**
	LNG CCGT	692	57	635	669	704	0.05	0.02	69.54	10.38	4.12	**89.80**	**93.63**

Source: IEA and OECD (2010: 59-61)

Jeong (2013) estimated the solar energy LCOE by power station in South Korea. In the paper, large power stations are indicated as having an electricity-generating capacity of more than 1MW, and small stations have a capacity between 20kW and 1MW. Samples of 380 solar energy power plants were examined in the paper. The following list shows the parameter values of Jeong’s calculation: O&M cost: 1%, Discount rate: 5.5%, Capacity Factor: 15.5%, Degradation, Factor: 0.7%, and System: 20 years. The cost of solar energy is also not competitive in economic terms, even though the costs have gradually decreased. In 2011, the costs were estimated with 291.59 US dollar if generated at a large power plant. Even though the LCOE of solar is approximately ten times more than that of nuclear energy’s, the installation unit cost and the LCOE are decreasing. In 2011, for example, the installation unit cost of 3.49 US dollars (large plant) was about twice as low than in 2007 (7.20 USD). The LCOE also decreased from 541.10 USD in 2007 to 291.56 USD in 2011.

Table 23. The Yearly average solar energy LCOE by capacity in South Korea

	Capacity factor (%)		Installation unit cost (USD/W)		LCOE (USD/MWh)	
Year	Large	Small	Large	Small	Large	Small
2005	-	12.1	-	15.09	-	1,406.07
2006	-	13.3	-	8.56	-	723.09
2007	15.0	15.1	7.20	9.45	541.10	703.52
2008	15.6	15.2	7.97	8.34	576.32	626.22
2009	14.8	14.9	7.22	7.41	550.88	568.49
2010	14.1	15.6	3.95	5.20	318.98	376.71
2011	13.4	14.1	3.49	4.44	291.59	360.08

Source: Jeong (2013: 54)[18]

[16] OPR-1000 is a Korean 1000 MWe PWR Generation II nuclear reactor. Optimized Power Reactor 1000
[17] APR-1400 is a Korean 1,400MW nuclear power reactor. Advanced Power Reactor 1400 (KEPCO- Korea Electric Power Corporation, 2014a)
[18] It is calculated from Korean Won to US dollars with currency rates at 1 US dollars = 1,022.00 Korean Won.

2.3.1.3. The LCOE of solar PV in Japan

The LCOEs of nuclear, coal-fired, and gas-fired electricity-generating technology in Japan are higher than in China and South Korea. Including overnight costs and investment costs, all categories are more expensive than in the two other countries. The LCOE of nuclear energy in Japan is 76.46 USD calculated with a 10 percent discount rate. The LCOE of coal-fired technology amounts to 107.03 USD, that of gas-fired to 119.53 USD.

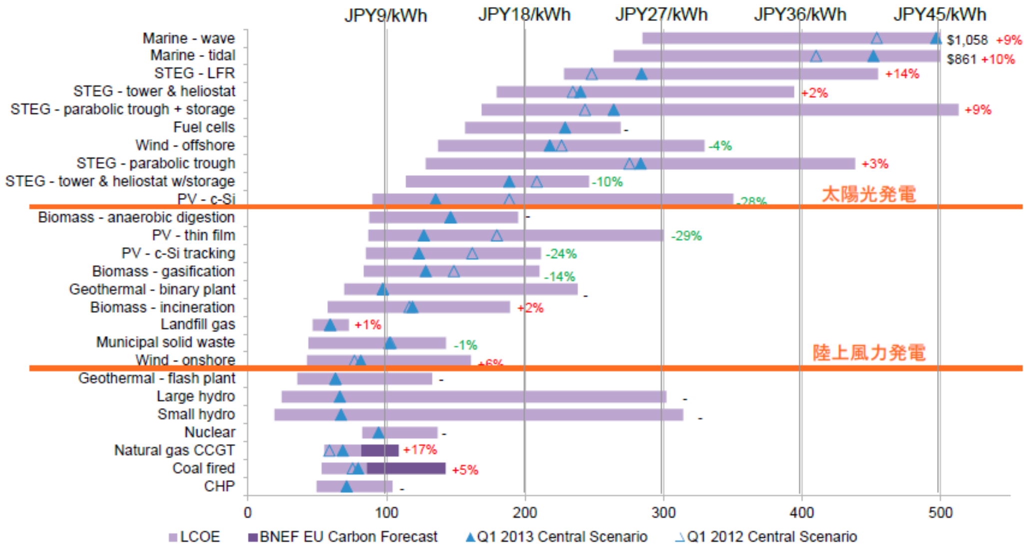
Table 24. Traditional energy plants: Levelized costs of electricity in US dollars per MWh in Japan

Technology		Net capa-city	ECE	Over-night costs	Investment costs		Decommissioning costs		Fuel Cycle costs	Carbon costs	O&M costs	LCOE	
					5%	10%	5%	10%				5%	10%
		MWe	%	USD/kWe	USD/kWe		USD/kWe		USD/MWh	USD/MWh	USD/MWh	USD/MWh	
Nuclear	ABWR[19]	1,330	-	3,009	3,430	3,940	0.13	0.01	9.33	-	16.50	**49.71**	**76.46**
Coal-fired	Black	800	41	2,719	2,935	3,166	0.11	0.02	31.61	23.88	10.06	**88.08**	**107.03**
Gas-fired	CCGT	1,600	55	1,549	1,863	2,234	0.12	0.04	72.58	11.02	5.55	**105.14**	**119.53**

Source: IEA and OECD (2010: 59-61)

The LCOE of the crystal-silicon solar PV technology in Japan is economically more attractive than marine-wave and tidal, fuel cells, and wind-offshore technologies in Japan. However, the LCOE of solar PV is still higher than that of biomass, geothermal, wind-onshore, large and small hydro power plants. The LCOEs of conventional energies such as nuclear, natural gas, and coal were assessed comparatively lower among all energy sources (Nakamura, 2013). The LCOE of the CSP technology is even higher than that of solar PV. The tower & heliostat and parabolic trough's LCOE present the highest LCOE except marine wave and tidal technology (Nakamura, 2013).

Figure 11. The LCOE of energy resources in Japan



Source: Nakamura (2013:8)

[19] ABWR: Advanced boiling water reactor.

Overall, the economic potential of solar energy still appears not economically attractive compared to other conventional energy sources. Considering societal external cost in the LCOE, it is also unattractive so far: Timilsina et al. (2011) calculated the LCOE of fossil fuels taking into account environmental damage costs ranging from 0 USD/tCO_2 to 100 USD/tCO_2. Even if calculated with environmental damage costs of 100 USD/tCO_2, the LCOE of solar energy is still higher than that of other fossil fuels (Timilsina et al. 2011).

2.4. Market potential

The market potential of solar energy describes the introduction of the technology into a market. As such, the demand for energy, competing technologies, the costs and subsidies of solar energy, as well as opportunities and barriers can be taken into account (Hoogwijk and Graus, 2008). The expected revenues and expenditures at market prices calculated with discount rates are also considered as part of the market potential (Verbruggen et al. 2009). Kreycik et al. (2010) state that the market potential is an estimation of the market considerations such as demand, supply, commodity prices, regulations, incentives, barriers, investments, and consumer response. The market potential is the quantity limited by realizable resources, technical-, economic-, and market-constraints. Kreycik et al. also define the goal-oriented potential study as a research that meets chosen policy-driven goals. Eyer and Corey (2010) point out that, in addition to the above, sales trends and projections, surveys, analyses of utility capital budget plans, and detailed product cost estimations can also be used as criteria for the market potential. Finally, the UNDP defines the market potential as follows.

> *The market trend potential—or expected potential—is the efficiency improvement that can be expected to be realized for a projected year and given set of boundary conditions such as energy prices, consumer preferences, and energy policies. The market trend potential reflects obstacles and market imperfections that keep efficiency potentials from being fully realized (UNDP 2000: 183).*

In light of the above, we will therefore analyze the energy market in general, its demand and supply and market trend, the prices of energy, electricity, and related products, concluded by an introduction of the major market players and an exhaustive policy analysis for all three countries.

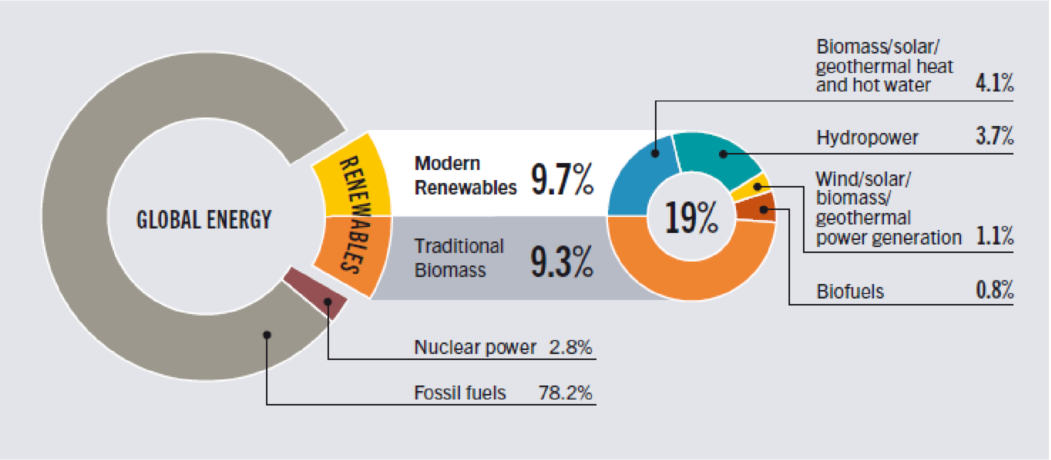
2.4.1. Overview of the solar energy market

In this section, the solar energy market, including the whole renewable energy market, will be examined in order to understand the renewable energy situation worldwide.

As of 2011, fossil fuels accounted for 78.2 percent of world energy consumption, whereas 2.8 percent were covered by nuclear power. Renewable energy, within the global final energy consumption, takes up 19 percent. Out of that, biomass, solar, geothermal heat and hot water account for 4.1 percent and hydropower represents 3.7 percent. Among the "modern renewables", wind-, solar-, biomass-, and geothermal power-generation cover only 1.1 percent so far (REN 21, 2013). The total renewable power capacity in the world is over 1,470 GW in

2012. Solar PV capacity covers 139 GW and concentrating solar thermal power makes up 3.4 GW. New investments in renewable power and fuels globally summed up to 249.4 billion USD in 2013 (REN21, 2014).

Figure 12. Estimated renewable energy share of global final energy consumption in 2011



Source: REN 21 (2013:19)

The gross renewable power capacity not including hydropower is 480 gigawatts in 2012. Wind power represents about 280 GW, Solar PV accounts for approximately 100 GW, and bio-power covers about 80 GW. China shows 90 GW of the total renewable power capacity. Out of that, wind power makes up about 74 GW, solar PV covers 7 GW, and Bio-power presents 9 GW in China. In comparison, the total renewable power capacity of the Unites States is 86 GW, and Germany has 71 GW (REN 21, 2013).

The development of renewable energy is fostered all across the world. China, USA, and Germany lead the total capacity of renewable energies. China takes the first position in the ranking of renewable power energy, hydropower, and wind power. USA stands in high ranks of renewable power, geothermal power, hydropower, wind power, and geothermal heat capacity. In the category of renewable power per capita, wind power, and geothermal heat capacity, Germany has highly developed the total capacity of renewable energies (REN 21, 2013).

Table 25. Top five countries of total capacity of renewable energy except solar energy as of 2012

	Renewable power (incl. hydro)	Renewable power (not incl. hydro)	Renewable power per capita(not incl. hydro)	Geothermal power	Hydropower	Wind power	Geothermal heat capacity
1	China	China	Germany	USA	China	China	USA
2	USA	USA	Sweden	Philippines	Brazil	USA	China
3	Brazil	Germany	Spain	Indonesia	USA	Germany	Sweden
4	Canada	Spain	Italy	Mexico	Canada	Spain	Germany
5	Germany	Italy	Canada	Italy	Russia	India	Japan

Source: REN21 (2013:17)

In the solar energy field, Germany and the USA are the leading countries. The countries which naturally receive much solar radiation are leading in the development of concentrating solar thermal power such as Spain, USA, Algeria, Egypt, Morocco, and Australia. These countries have the world best solar radiation potential in terms of theoretical potential. However, Germany ranks first in solar PV area even though it has comparatively less solar resources. Germany covers 32 percent of the global solar PV capacity. Italy takes up 16 percent and the United States accounts for 7.2 percent. China and Japan rank fourth and fifth representing 7 percent and 6.6 percent in terms of solar PV capacity but do not enter the top five when we look at solar PV per capita (REN 21, 2013).

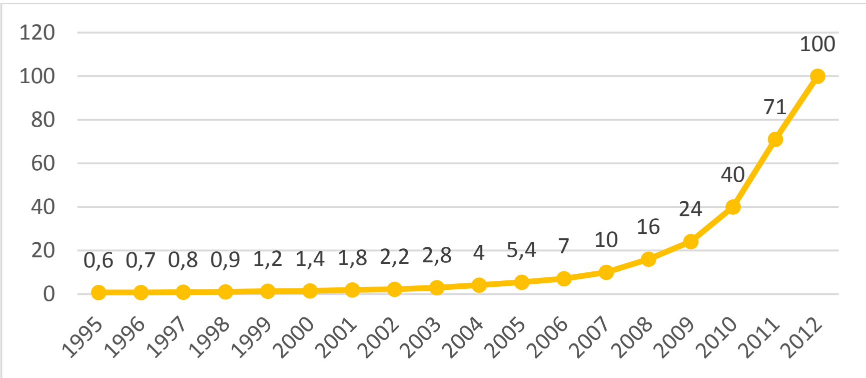
Table 26. Top five countries of total capacity of solar energy as of 2012

	Concentrating solar thermal power (CSP)	Solar PV(% of share)	Solar PV per capita
1	Spain	Germany (32.0)	Germany
2	USA	Italy (16.0)	Italy
3	Algeria	USA (7.2)	Belgium
4	Egypt/Morocco	China (7.0)	Czech Republic
5	Australia	Japan (6.6)	Greece

Source: REN21 (2013:17)

The global Solar PV capacity has been increasing dramatically during last ten years. The total capacity in the world in 1995 was only 0.6 GW, reached 1.4 GW in 2002, and a total of 100 GW in 2012. Average annual growth rates of solar energy technologies are higher than all other renewable energy technologies. Especially, the growth rate of concentrating solar thermal power rose from 43 percent in 2007 to 61 percent in 2012 and. Solar PV has also been highly developed. The growth rate of the market showed 42 percent in 2012, during the years 2007 and 2012 even 60 percent. In comparison, the growth rate of Hydropower generation in 2012 was 3.1 percent, geothermal power showed 2.6 percent, and Biodiesel production grew by 0.4 percent (REN 21, 2013).

Figure 13. Solar PV global capacity 1995-2012 (unit: Gigawatts)



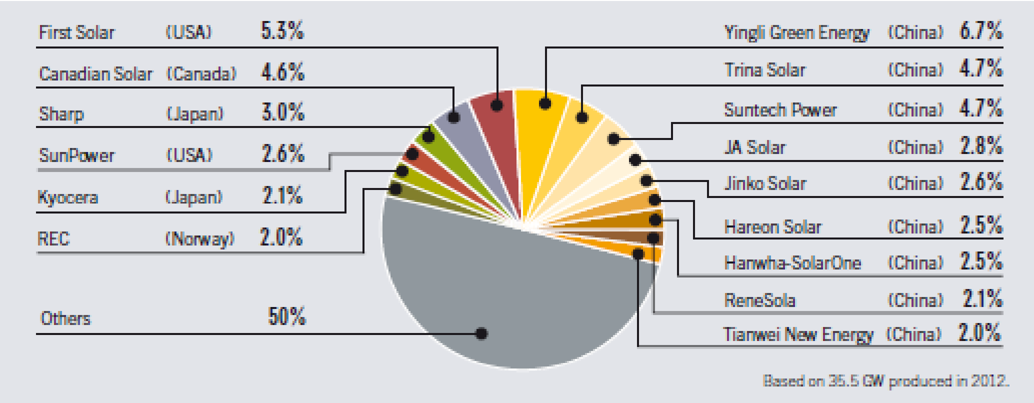
Source: REN 21 (2013:41)

About 31.9 GW of crystalline silicon cells and 35.5 GW of modules were manufactured in 2012. Asia currently leads the module production over the world, with a share of 86 percent of global production. China produces two-thirds of the world total production of solar energy modules in 2012 (REN 21, 2013).

The year 2012 was a difficult one for the solar PV industry. More than 24 American, 10 European, and 50 Chinese solar manufacturers have left the industry during 2012. Bosch solar (Germany) decided to stop producing cells and panels and Siemens (Germany) announced to quit solar business (REN 21, 2013). When we look at the market shares of PV module manufacturers, Chinese companies lead the market having 30.6 percent market share. Among

Chinese market leaders, Yingli Green energy takes up 6.7 percent, First Solar accounts for 5.3 percent, and Trina Solar and Suntech Power present 4.7 percent each (REN 21, 2013).

Figure 14. Market shares of top 15 solar PV module manufacturers, 2012

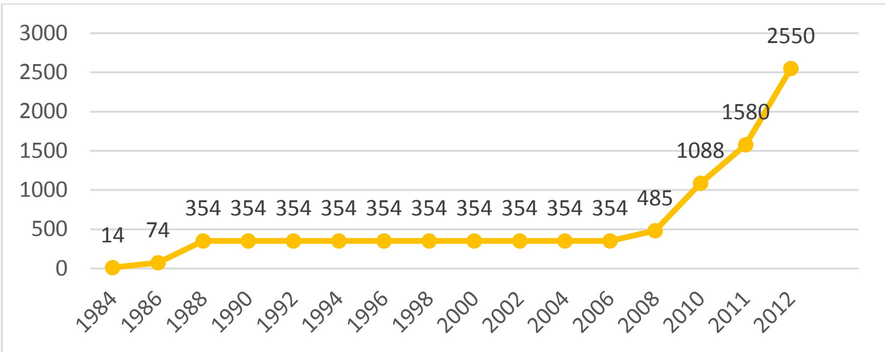


Source: REN21 (2013:41)

The global capacity of concentrating solar thermal power has noticeably developed during the last 30 years. The capacity amounted to only 14 MW in 1984, it reached 495 MW in 2008, and rose to 2,550 MW in 2012. Out of those, 970 MW are generated in Spain, the world-leading country in the CSP market. The USA takes in the second position on the market, generating 507 MW. The Ivanpah plant that will be the world largest having 392 MW is under construction in California's Mojave Desert. The power of 392 MW is able to supply electricity for 140,000 U.S homes (REN 21, 2013).

Spanish companies accounting for three-fourths of the global CSP capacity take the lead in the CSP industry. Chinese companies started to try to enter the CSP market. The CSP needs large amounts of capital investment. Therefore, individual companies require a large share along the value chain like technology, R&D, project operation and ownership. The emergence of supply chains mainly occurs in Spain and the USA (REN 21, 2013).

Figure 15. Concentrating solar thermal power global capacity, 1984-2012 (unit: megawatts)



Source: REN 21 (2013:45)

Solar water heating global capacity has gradually increased during the last 10 years. The capacity was 44 GW in 2000, it 105 GW in 2006, and 255 GW in 2012. Among solar water heating global capacity, China marks 68 percent among a total of 223 GW. Germany present 4.6 percent, and Japan accounts for 1.5 percent (REN 21, 2013).

Approximately 5.7 million people are directly and indirectly working in the renewable energy market during 2009 - 2012. An estimated number of 2.3 million people work in the solar energy field. In China, about 1.7 million workers make an effort for the solar energy industry. Comparing to wind power, about 18 times more jobs are offered in the solar energy area (REN 21, 2013).

Table 27. Estimated direct and indirect jobs in renewable energy worldwide, by industry (unit: thousand jobs)

Technologies	Global	China	EU	Brazil	USA	India	Germany	Spain
Biomass	753	266	274	-	152	58	57	-
Biofuels	1,379	24	109	804	217	35	23	39
Biogas	266	90	71	-	-	85	50	4
Geothermal	180	-	51	-	35		14	1
Hydropower	109	-	24	-	8	12	7	0.3
Solar PV	1,360	300	312	-	90	112	88	2
CSP	53		36	-	17	-	2	12
Solar heating/ cooling	892	800	32	-	12	41	11	134
Wind power	75	267	270	29	81	48	118	28
Total	5,745	1,747	1,179	833	611	391	378	120

Source: REN 21 (2013:53)

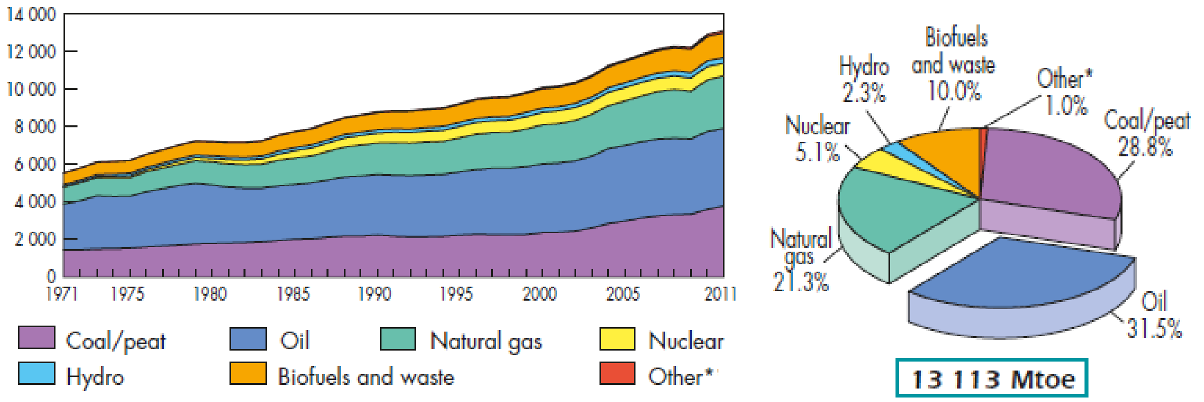
2.4.2. Demand and supply, Market trends

In this part, the demand and supply of conventional energies such as oil, gas, and nuclear power will be examined. Through comparing to the energies' quantity and percentage, the situation and scope of energy market in each nation will be analyzed. What is more, the trend of renewable energy is shown as an important criterion for the market potential because we are able to see which renewable energy is significant in each country. In other words, even though the potential of solar energy would be abundant, wind power could be preferred if it shows a higher potential. Moreover, the trend of renewable energy shows the tendency of renewable energy development in each country.

2.4.2.1. General overview of the energy market

The total quantity of the energy supply amounts to 13,113 Mtoe in 2011 and has ever increased since 1971. The most widely used energy source is oil (31.5%) followed by coal and peat (28.8%) and natural gas (21.3%). Biofuels and waste, nuclear, hydro, and other energy-generating sources (geothermal, solar, wind, heat, etc) account for 10.0, 5.1, 2.3, and 1.0 percent, respectively (IEA, 2013).

Figure 16. World total primary energy supply from 1971 to 2011 (left) and its share in 2011 (right)



Source: IEA (2013:6)

The total energy trend in China, South Korea, and Japan from a global perspective presents itself as follows: Looking at the global producers, importers, and installed capacity of energy resources, the three East Asian countries account for large portion of it. The IEA examined world energy statistics by nation as shown in table 28. The numbers given to some countries indicate the world ranking (results are based on 2011). China ranks first in producing and importing coal, and on the seventh place of producing natural gas. In fact, China, South Korea, and Japan are the main importers of natural gas and coal. The three nations take up 24.9 percent of natural gas imports, 49.5 percent of coal imports, and 20.3 percent of nuclear installed capacity in the world. The quantity of hydro power, in comparison, makes up 19.6 and 2.6 percent in China and Japan. 194 GW of hydro power are installed in China and 48 GW in Japan, among 999 GW which is the world total installed capacity of hydro power.

Table 28. Global producers, importers, installated capacity of natural gas, coal, and nuclear

Natural gas				Coal				Nuclear			
Producer	bcm[20]	Net importers	bcm	Producers	Mt[21]	Net importers	Mt	Producers	TWh	Net installed capacity	GW
USA	681	**Japan**	122	**China**	3,549	**China**	278	USA	821	USA	102
Russia	656	Germany	70	USA	935	**Japan**	184	France	442	France	63
Qatar	160	Italy	68	India	595	India	158	4. **Korea**	155	**Japan**	44
Iran	158	**Korea**	48	Indonesia	443	**Korea**	126	6. **Japan**	102	5. **Korea**	19
7. **China**	107	9. **China**	36	Australia	421	Taipei	65	9. **China**	86	9. **China**	12
World	3,435	World	827	World	7,831	World	1,188	World	2,584	World	369

Source: IEA (2013)

The percentage of crude oil imports, oil products, and crude distillation capacity in the three East Asian countries are 26.6, 18.3, and 21.7, respectively. The refinery imports from the countries amount to 27.1 percent.

[20] bcm: billion cubic meters
[21] Mt: Million tonnes

Table 29. Global producers, importers, the capacity of crude oil, oil product, and refinery

Crude oil				Oil product				Refinery			
Producers	Mt	Net importers	Mt	Producers	Mt	Net importers	Mt	Crude Distillation capacity	Kb/cd[22]	Net importers	Mt
Saudi Arabia	544	USA	500	USA	824	**Japan**	34	USA	17,647	USA	439
Russia	520	**China**	251	**China**	417	**China**	25	**China**	13,410	**China**	276
USA	387	**Japan**	177	Russia	248	Indonesia	22	Russia	5,605	**Japan**	211
China	206	India	172	**5. Japan**	169	Mexico	22	4. **Japan**	4,574	India	125
Iran	186	5. **Korea**	125	**6. Korea**	127	France	19	6. **Korea**	3,053	6. **Korea**	106
World	4,142	World	2,079	World	3,896	World	430	World	96,884	World	2,186

Source: IEA (2013)

Another form of energy is measured in terms of electricity, which is imperative for human beings. The generation trend of electricity by fuel will be also explored. First of all, we are able to compare the national generation quantity through the below table 30. When we look at the 2010 statistics, China, South Korea, and Japan generated 4,227,800, 432,748, and 918,236 GWh, respectively. The amount of electricity generation in China exceeded that of the U.S.A, which was 2,503,839 GWh in 2010. In comparison, the total electricity generation in France, Germany, and the United Kingdom in 2011 reached 459,700, 462,102, and 332,312 GWh, respectively. In this year, South Korea's electricity quantity already overtook these three countries. Thermal power is the most widely used source for generating electricity in the three East Asian countries. It is noticeable that Japan's 2011 nuclear generation dropped to a half of that in 2010. Overall, the total electricity generation in Japan is decreasing while the generation of China and Korea is increasing (Electric Power Statistics Information System-EPSIS, 2013).

Table 30. Electricity generation by source and country (Unit: GWh)

	2011					2010				
	Hydro	Thermal power	Nuclear	etc	Total	Hydro	Thermal power	Nuclear	etc	Total
China	-	-	-	-	-	686,700	3,416,600	70,100	54,400	**4,227,800**
Korea	7,831	325,933	154,723	7,593	**496,080**	5,641	277,545	147,771	1,791	**432,748**
Japan	74,378	678,527	101,761	2,739	**857,405**	74,175	553,264	288,230	2,567	**918,236**
	2008					2007				
	Hydro	Thermal power	Nuclear	etc	Total	Hydro	Thermal power	Nuclear	etc	Total
China	565,500	2,803,000	69,200	13,300	**3,451,000**	471,400	2,720,700	62,900	9,400	**3,264,400**
Korea	5,563	265,105	150,958	0	**421,626**	5,042	254,315	142,937	0	**402,294**
Japan	75,914	621,286	258,128	2,561	**957,889**	76,853	661,083	263,832	2,854	**1,004,622**

Source: EPSIS (2013)

The electricity production from coal and peat in the three countries takes up 46.2 percent of worldwide production in 2011. The electricity of 374 TWh in Japan and 116 TWh in South Korea were generated by natural gas out of 4,852 TWh world total. 28.4 percent of total electricity production is generated in China, Japan, and South Korea (IEA, 2013).

Turning to renewable electricity generation, the gross global renewable electricity generation in 2013 was 5,136 TWh. The electricity generation by hydro power is the most used source; producing 3,888 TWh in 2013 and thus being the largest used renewable resource in the world. Wind (626 TWh) and bio power (396 TWh) were the second and third most used

[22] Kb/cd: thousand barrels per calendar day

renewable electricity generation sources. What is more, a more than fortyfold increase in electricity generation through solar PV, and a fourteen fold increase in CSP technology could be noted during the last ten years. 138 TWh of Solar PV and 9 TWh of solar CSP were produced for electricity generation in 2013. Overall, the sums of global renewable electricity generation have steadily increased since 2005 (IEA, 2012b; 2013).

Table 31. World renewable electricity generation (TWh)

Sources	2005	2006	2011	2012	2013	2014 (estimated)
Ocean	1	1	1	1	1	1
Geothermal	58	60	70	72	77	80
Solar CSP	**1**	**1**	**3**	**6**	**9**	**14**
Solar PV	**4**	**6**	**62**	**100**	**138**	**178**
Wind	103	133	438	519	626	725
Bio	198	209	352	373	396	428
Hydro	3,018	3,122	3,567	3,792	3,888	4,010
Total	3,381	3,531	4,492	4,862	5,136	5,436

Source: IEA (2012b, 2013)

In the following chapters, the focus now turns to the specific situation of supply and demand as well as renewable electricity trend in each of the three countries.

2.4.2.2. Demand, supply and trends in China

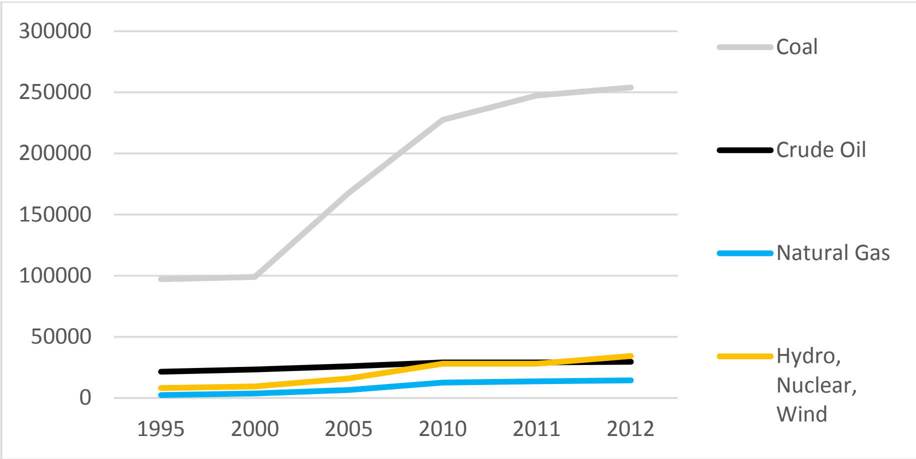
In order to analyze the demand and supply of energy in China, the total production and consumption of energy including the share of energy source production, energy imports and exports, and electricity generation will be explored. What is more, the trend of renewable energy will be shown.

Total energy production, consumption, and composition in China

In China, coal is by far the most important source of energy. The production sums up to over 2.5 billion SCE[23] in 2012. The production quantity of coal in 2012 was five times higher than 30 years before. Furthermore, crude oil production reached a quantity of 295 million tons of SCE in 2012. The production of natural gas amounted to 142 million tons of SCE which denotes about a sevenfold increase compared to 1995's statistics. On the other hand, 341 million tons of SCE of Hydro-power, nuclear, and wind power were produced in 2012. The quantity rose about four times compared to the year 1995. Referentially, the energy production quantity statistics of hydro-power, nuclear, and wind are combined by the NBSC. For a more exact analysis of those three sources of energy, more detailed data would be necessary.

[23] SCE (Standard Coal Equivalent): A measurement of energy generated by burning coal 1kWh=0.123 kg SCE.

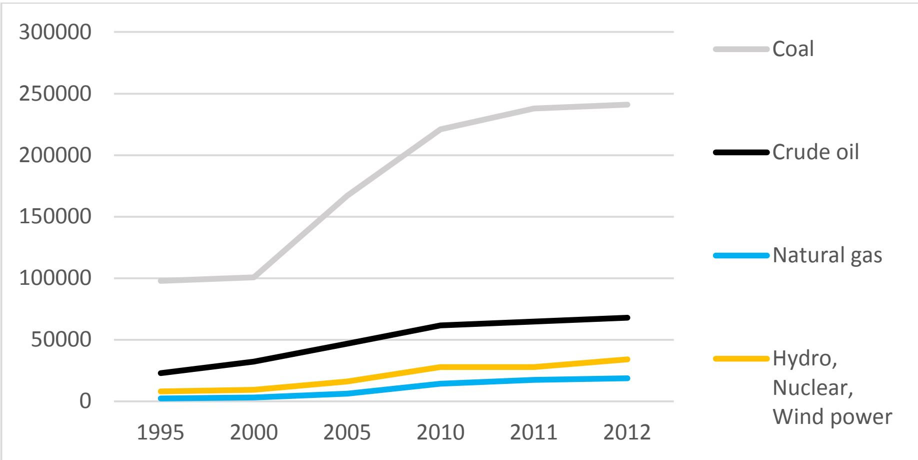
Figure 17. Total production of energy in China (Unit: 10,000 tons of SCE)



Source: own-figure based on NBSC (2013)

Similar to the development of energy production, the total energy consumption in China shows an increase of approximately three times since 1995. Coal is definitely the most consumed energy source in China with 2.4 billion tons of SCE in 2012. 680 million tons of SCE of crude oil were used and 188 million tons of SCE of natural gas were consumed in 2012. In addition, 340 million tons of SCE of hydro, nuclear, and wind power were used in 2012.

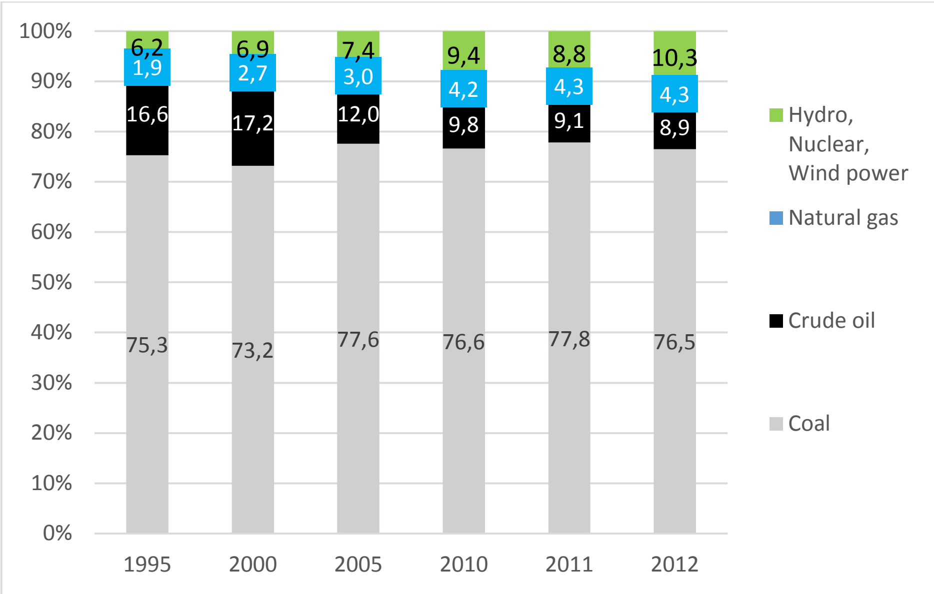
Figure 18. Total consumption of energy in China (Unit: 10,000 tons of SCE)



Source: own-figure based on NBSC (2013)

Looking at the total energy production composition, figure 19 shows the shares of energy resources: Coal accounted for 76.5 percent, oil represented 8.9 percent, natural gas covered 4.3 percent, and hydro, nuclear, and wind power made up 10.3 percent in 2012. The percentage of coal consumption in China seems to have stabilized between 1995 and 2012. The consumption share of crude oil has decreased while that of natural gas and hydro, nuclear, and wind power has increased since 1995.

Figure 19. Total energy production composition in China



Source: own-figure based on NBSC (2013)

Energy import and export in China

China is the world second-largest crude oil importing country in the world (CIA, 2014). The amount of imported refined petroleum in 2010 was 971.5 million barrels per day. The amount of the imported petroleum had somewhat fluctuated between 2006 and 2010. The quantity of imported natural gas in China steadily increased to 1,471 billion cubic feet per year in 2012. 318.5 million short tons of coal were imported in 2012 in China. The amount of imported coal in 2010 rose by approximately eight times compared to 2006.

Table 32. Energy imports in China

		2006	2007	2008	2009	2010	2011	2012
Refined petroleum (Thousand Barrels per day)	Motor gasoline	1.43	5.30	46.44	1.03	0	NA	NA
	Jet fuel	75.54	80.99	83.69	74.02	86.97	NA	NA
	Kerosene	45.15	32.08	55.61	57.43	18.36	NA	NA
	Distillate fuel oil	14.41	33.13	127.64	39.34	36.79	NA	NA
	Residual fuel oil	510.78	441.04	398.89	497.02	419.49	NA	NA
	Liquefied petroleum gases	170.22	128.84	82.38	129.67	103.92	NA	NA
	Other products	97.67	151.75	146.70	303.78	206.97	NA	NA
Total		915.19	873.14	941.34	1,102.29	971.50	NA	NA

Natural gas (Billion cubic feet per year)	33	138	159	264	577	1,108	1,471
Coal (Thousand short tons per year)	42,005	56,236	44,467	138,890	179,870	200,722	318,465
Electricity (Billion kilowatt hours)	5.39	4.25	3.84	6.01	5.54	6.56	6.87

Source: EIA (2014c)

The amount of refined petroleum in China had also increased between 2006 and 2010, reaching 623.4 million barrels per day in 2010. While the amount of exported natural gas had changed little, that of coal decreased since 2006 to 15.2 million short tons in 2012.

Table 33. Energy exports in China

		2006	2007	2008	2009	2010	2011	2012
Refined petroleum (Thousand Barrels per day)	Motor gasoline	81.91	108.51	47.53	114.96	120.82	NA	NA
	Jet fuel	0	0	0	0	0	NA	NA
	Kerosene	78.59	94.90	113.60	125.84	128.13	NA	NA
	Distillate fuel oil	15.86	13.51	12.90	97.84	94.83	NA	NA
	Residual fuel oil	47.09	69.28	133.51	157.36	180.64	NA	NA
	Liquefied petroleum gases	4.80	10.74	21.58	26.98	29.56	NA	NA
	Other products	104.19	91.68	92.21	88.14	69.42	NA	NA
Total		332.45	388.62	421.33	611.11	623.41	NA	NA
Natural gas (Billion cubic feet)		106	95	119	113	142	113	101
Coal (Thousand short tons)		85,626	75,409	63,384	25,235	27,181	27,546	15,184
Electricity (Billion kilowatthours)		12.27	14.57	16.64	17.39	19.06	19.32	17.65

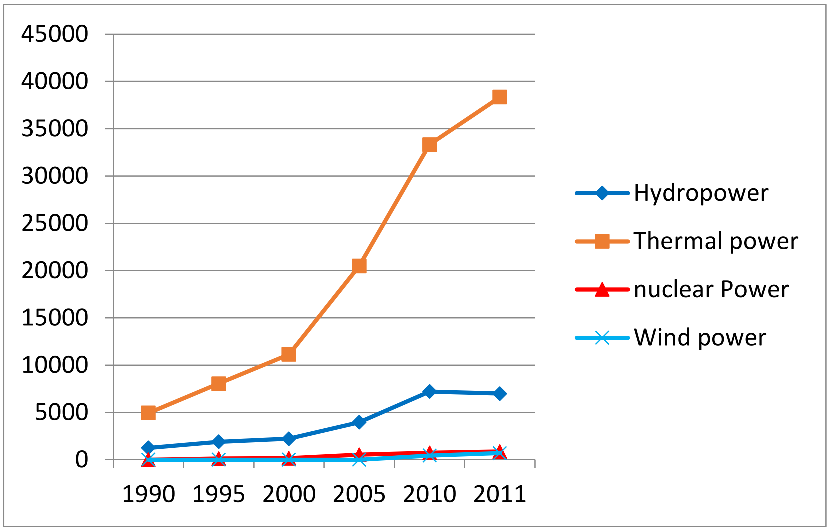
Source: EIA (2014c)

Overall, the total quantity of energy production and consumption is on an increasing trend. Coal is the most widely produced and used energy source in China, taking up more than seventy percent in the share of energy production and consumption. The trend of energy imports especially coal and natural gas has been on the rise. The tendency of exporting petroleum and natural gas is increasing whereas that of coal is sharply decreasing. Looking at renewable energy sources, they still account for a small proportion among all energy sources. It is hard to distinguish the exact portion of solar and renewable energy among all energy sources because the figures of hydro, nuclear, and wind power are not explicated in the NBSC's statistics. However, data on renewable electricity generation is available and will be shown in the next chapter.

Electricity balance in China

Among all electricity-generating sources, thermal power is mostly used in China. In 2011, 3.83 trillion kWh of thermal power, 698.9 billion kWh of hydropower, 86.3 billion kWh of nuclear power, and 70.3 billion kWh of wind power were used to generate electricity. In relative terms, thermal power, hydro, nuclear, and wind accounted for 78.4, 14.3, 1.8, and 1.4 percent, respectively.

Figure 20. China's installed electricity capacity by fuels 2012 (Unit: 100 million kWh)

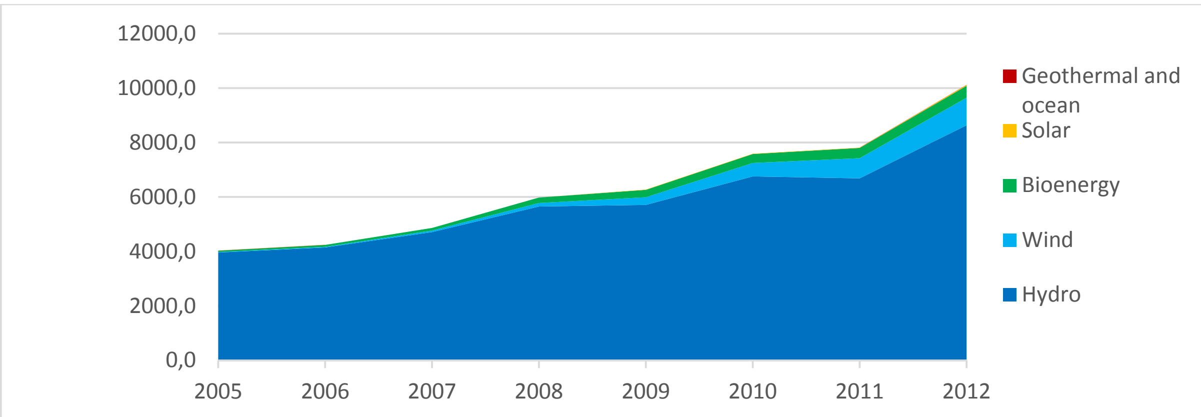


Source: own-figure based on National Bureau of Statistics of China (2013)

Renewable electricity generation trend and solar PV installation in China

Total renewable electricity amounted to 1.01 trillion kWh in 2012. Traditionally, hydro power has been used most, its quantity almost doubled from 396.4 billion kWh in 2005 to 864.1 billion kWh in 2012. Wind power electricity generation has been dramatically fostered since 2005. 100.4 billion kWh of wind power were generated in 2012 whereas only 1.6 billion kWh were produced in 2005. The values of bio energy are also growing. In 2012, 44.0 billion kWh of bio energy electricity were generated while 5.2 kWh were provided in 2005. Solar, geothermal and ocean electricity generation accounted for only a small portion among total renewable electricity generation. However, the tendency of geothermal, ocean and solar power generation is rising upwards. There was a thirty-fivefold increase in solar electricity generation over the analyzed seven-year period, marking an increase from 100 million kWh in 2005 to 3.5 billion kWh in 2012.

Figure 21. Renewable electricity generation in China (Unit:100million kWh)

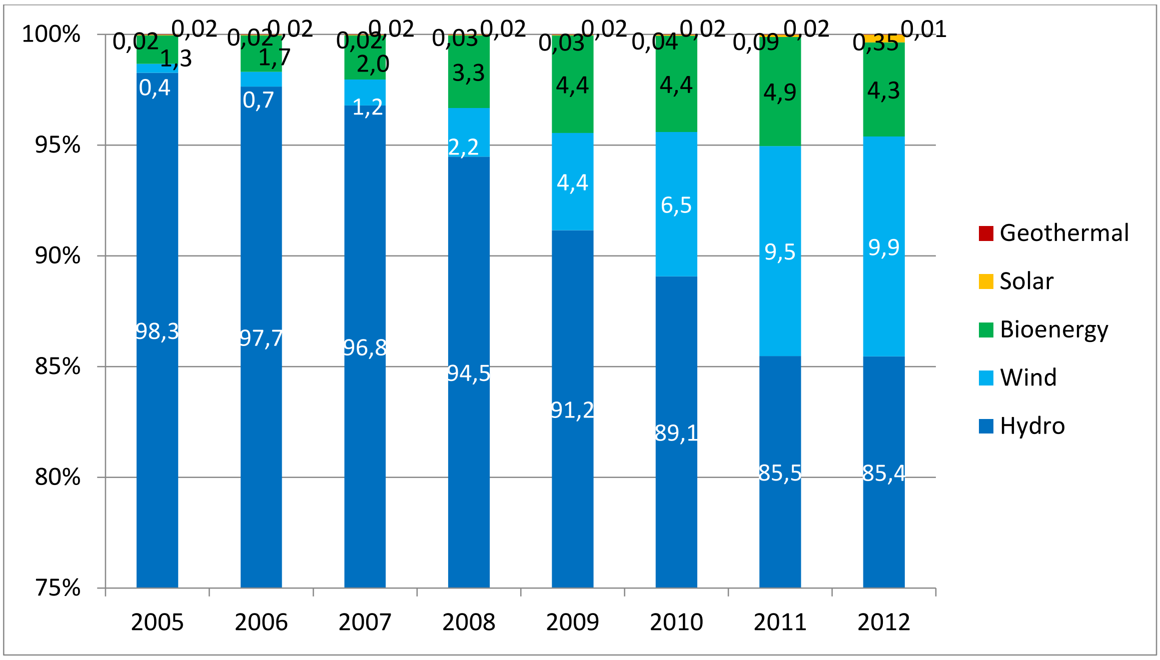


Sources	2005	2006	2007	2008	2009	2010	2011	2012
Geothermal and ocean	1.0	1.0	1.0	1.0	1.0	1.5	1.5	1.5
Solar	**1.0**	**1.0**	**1.0**	**2.0**	**2.0**	**3.0**	**7.0**	**35.0**
Bioenergy	52.0	70.0	97.4	196.2	276.0	330.0	385.0	440.0
Wind	16.0	28.0	57.0	131.0	276.0	494.0	741.0	1,004.0
Hydro	3,964.0	4,148.0	4,714.0	5,655.0	5,717.0	6,759.0	6,681.0	8,641.0
Total	4,034.0	4,248.0	4,870.4	5,985.2	6,272.0	7,587.5	7,815.5	10,121.5

Source: China Renewable Energy Information Portal (2013)

Again, one can confirm that Hydro energy accounts for the majority among renewable energy electricity generation in China. The percentage for hydro energy in renewable power generation was 98.3 percent in 2005 but fell to 85.4 percent in 2012, in favor of wind power and bio energy that grew from 0.4 and 1.3 percent in 2005 to 9.9 and 4.3 percent in 2012. The share of solar energy also shows an upwards trend. The percentage was 0.02 percent in 2005 yet was 0.35 percent in 2012. However, in comparison to the other renewable energy sources, solar power only accounts for a small minority in China. Also, geothermal energy only makes up a small amount, recording 0.01 percent at a stable level.

Figure 22. The share of renewable energy electricity generation in China (2005-2012)



Source: own-figure based on China Renewable Energy Information Portal (2013)

The solar PV capacity in China remarkably has increased since 2009. The solar PV capacity in 2009 was 300 WM while the capacity became 18,300 MW in 2013. 160 MW of solar PV was installed in 2009 whereas 11,300 MW was installed in 2013.

Table 34. Domestic solar PV capacity in China (2009-2013) (Unit: MW)

	2009	2010	2011	2012	2013
Capacity	300	800	3,300	8,300	18,300
Installed per year	160	500	2,500	5,000	11,300

Source: Xu et al. (2012); IEA-PVPS (2014)

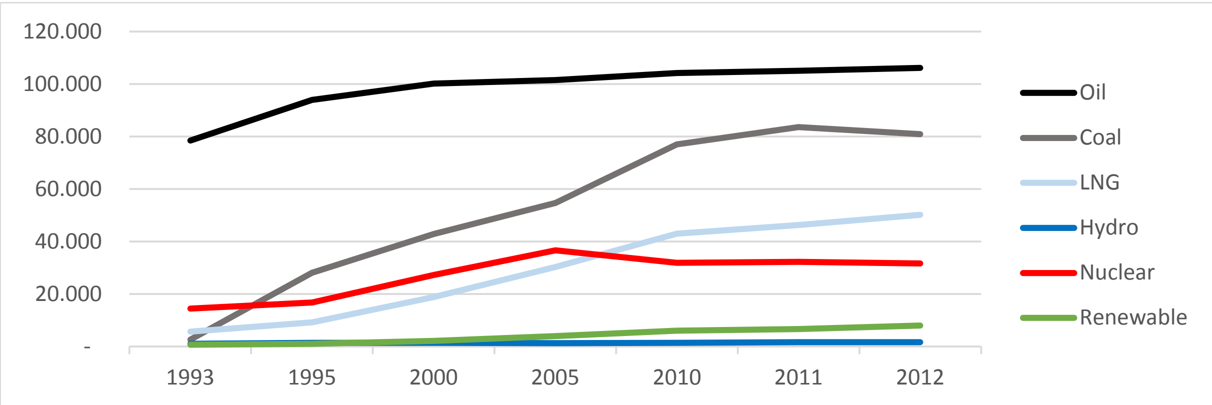
2.4.2.3. Demand, supply and trends in South Korea

Energy supply, consumption, and consumption rate by fuel in South Korea will be explored firstly in this chapter. Energy imports and exports in South Korea will be analyzed secondly. Lastly, the electricity balance and renewable energy electricity generation in South Korea will be presented.

Energy supply, consumption, and consumption rate by fuel in South Korea

It is estimated that South Korea was the ninth-largest energy consuming country in 2011. The nation depends largely on energy imports, which account for approximately 97 percent. In spite of lacking energy reserves, South Korea is one of largest and most advanced oil refining countries (EIA, 2014e). In South Korea, oil has been the most important energy source since 1993, using 106,165 toe[24] in 2012. In that year, twice as much oil had to be supplied in comparison LNG and three times more than nuclear power. However, South Korea does not have crude oil production as it does not possess oil reservoirs. A total of 80,978 toe of coal, 50,185 of LNG, 1,615 of hydro, 31,719 of Nuclear, and 8,036 of renewables were provided in South Korea in 2012. The supply of coal, and LNG increased about four and ten times between 1993 and 2012. Hydro power provision has been comparatively stable, whereas the supply of renewable energy has slightly increased since 1993. In relative terms, however, the quantity of supplied renewables was eleven times higher compared to the quantity of 1993 (KEMCO, 2014a).

Table 35. Energy supply in South Korea (unit: thousand toe)



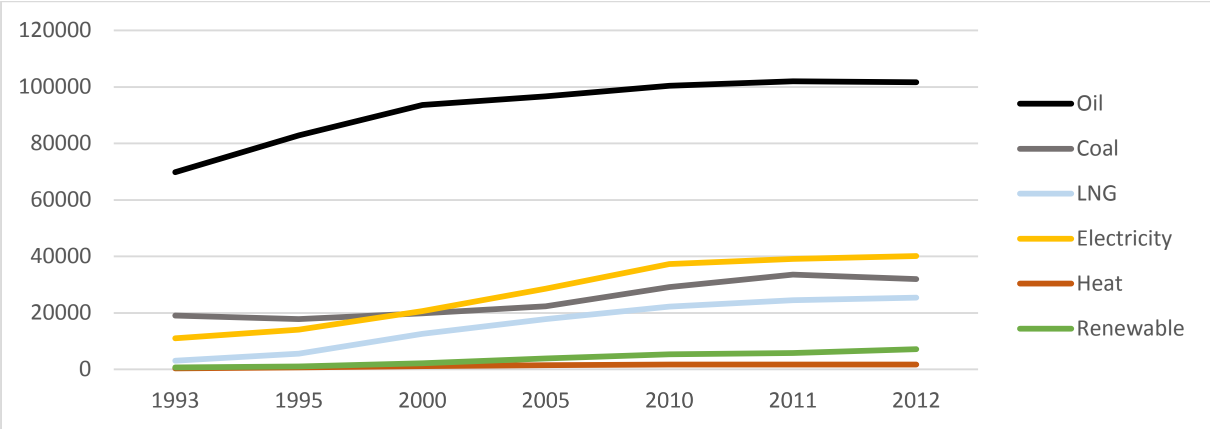
Source	1993	1995	2000	2005	2010	2011	2012
Oil	78,496	93,955	100,280	101,527	104,301	105,146	106,165
Coal	25,882	28,092	42,911	54,788	77,092	83,640	80,978
LNG	5,723	9,213	18,924	30,355	43,008	46,284	50,185
Hydro	1,502	1,369	1,402	1,297	1,391	1,715	1,615
Nuclear	14,535	16,757	27,241	36,695	31,948	32,285	31,719
Renewables	742	1,051	2,130	3,961	6,064	6,618	8,036
Total	126,880	150,437	192,888	228,623	263,804	275,688	278,698

[24] TOE=Tonnage of oil equivalent: unit of energy amount by burning one ton of crude oil. 1toe=11.63 megawatt hours.

Source: KEMCO (2014a)

Looking at the energy consumption in South Korea, the consumption of oil is remarkable in comparison to other energy sources. 101,710 thousand toe of oil were consumed in 2012, which is three times as much as coal (31,964), four times as much as LNG (25,445), and 2.5 times the value of electricity (40,127). 1,751 thousand toe of heat, and 7,124 of renewables were used in 2012. The quantity of oil, coal, and LNG generally keeps increasing since 1993. The consumption of LNG in 1993 was 3,027 thousand toe whereas it was 25,445 thousand toe in 2012. The consumption of electricity in 2012 rose fourfold compared to 1993. The use of Heat (1,751 thousand toe) is growing as well, and the number indicating renewable energy consumption (7,124 thousand toe) became approximately ten times higher than in 1993 (KEMCO, 2014a).

Table 36. Energy consumption in South Korea (unit: thousand toe)

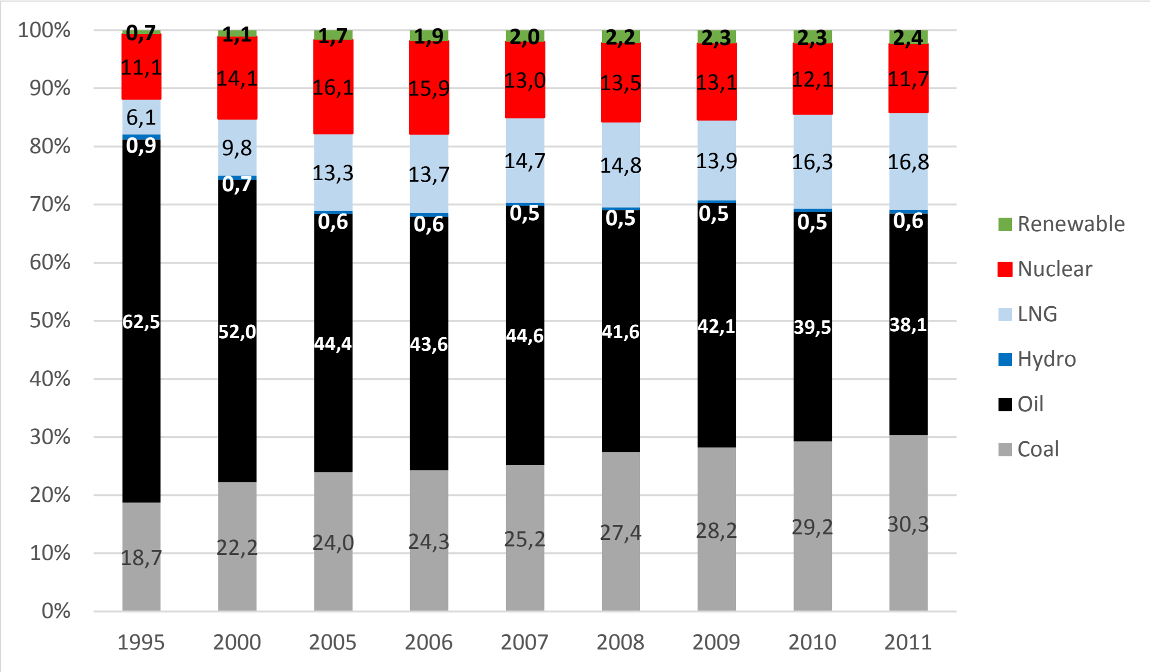


Source	1993	1995	2000	2005	2010	2011	2012
Oil	69,876	82,876	93,596	96,719	100,381	101,976	101,710
Coal	19,058	17,758	19,847	22,311	29,164	33,544	31,964
LNG	3,027	5,594	12,561	17,811	22,239	24,473	25,445
Electricity	10,985	14,041	20,600	28,588	37,338	39,136	40,127
Heat	360	641	1,118	1,530	1,718	1,702	1,751
Renewable	742	1,051	2,130	3,896	5,346	5,834	7,124
Total	104,048	121,961	149,852	170,855	196,186	206,665	208,121

Source: Korea Energy Management Corporation (2014)

When we see the share of energy consumption by fuel type in South Korea, the different sources balanced out to a certain extent: Whereas in 1995, South Korea depended heavily on oil (62.5 percent) in relation to all energy sources, but reduced the use of oil to 38.1 percent in 2011. On the other hand, coal, hydro power, LNG, nuclear power, and renewable energy sources represented the share of 30.3, 0.6, 16.8, 11.7, and 2.4 percent, respectively, in 2011.

Figure 23. Total energy consumption percentage by fuel type in South Korea (1995-2011)



Source: MKE - Ministry of Knowledge Economy and KEEI – Korea Energy Economics Institute (2012)

Energy imports and exports in South Korea

The domestic production of energy resources in South Korea is mainly based on coal products and on hydro power. For example, 10,324 thousand toe of total coal products and 7,652 GWh of hydro power were produced in 2012. What is more, since 2005 LNG has been collected and 334 thousand tons of LNG were produced in 2012. Resulting from its heavy use of oil, South Korea has therefore traditionally been importing this resource, ranking fifth of all oil importing countries in the world in 2012 (CIA, 2014). In 2012, 827,679,000 barrels (bbl) of oil were imported into South Korea. In addition, 125,858 thousand tons of coal and 150,328 GWh of nuclear power were imported in 2012. What is more, 38,151 thousand tons of LNG were brought to South Korea in 2012. The dependency rates on energy import are therefore enormously high. Between 1993 and 2012, the rates were mostly more than 95 percent. There are no exports of natural gas, coal, and electricity in South Korea (EIA, 2014c).

Table 37. Domestic production and import of energy in South Korea

	Source	1993	1995	2000	2005	2010	2011	2012
Domestic production	(anthracite) Coal (thousand ton)	9,749	5,367	4,159	4,347	2,508	2,239	2,288
	Hydro (GWh)	6,006	5,478	5,610	5,189	6,472	7,831	7,652
	LNG (thousand ton)	-	-	-	398	415	347	334
	Firewood and charcoal etc (thousand toe)	742	1,051	2,130	3,961	6,064	6,618	8,036
Domestic total (thousand toe)		6,631	4,835	5,404	7,732	9,161	9,794	11,116

Import	Coal (thousand ton)	32,670	38,985	62,367	80,475	118,521	128,621	125,858
	Oil (thousand bbl[25])	564,575	677,209	742,557	761,080	794,278	801,642	827,679
	Nuclear (GWh)	58,138	67,029	108,964	146,779	148,596	154,723	150,328
	LNG (thousand ton)	4,402	7,087	14,557	22,952	32,669	35,256	38,151
Import total (thousand toe)		120,249	145,602	187,485	220,890	254,644	266,842	267,582
Gross total		126,879	150,438	192,888	228,622	263,805	276,636	278,698
Import dependence rate (%)		94.8	96.8	97.2	96.6	96.5	96.5	96.0

Source: KEMCO (2014a)

Electricity balance in South Korea

There is a wide scope of electricity power supply and demand in South Korea, as can be seen in the below table. Since 2007, the power of installed capacity and average power have increased steadily. The installed capacity was 67,196 MW in 2007 and it increased to 86,969 MW in 2013. The average power amounted to 46,019 MW in 2007 and 58,426 MW in 2013. On the other hand, the amount of supply capacity, backup power, and maximum electric power fluctuated between in 2007 and 2013. Maximum electric power reached a peak of 75,987 MW in 2012 and fell again in the following year.

As of 2013, the total installed capacity in South Korea reached 86,969 MW. Supply capacity, which is a reduced amount of installed capacity and describes the actual capacity to generate supply of energy, amounted to 75,937 MW. The backup power that is prepared for the case when the electric power cannot be balanced was 5,611 MW. Maximum electric power was 70,326 MW while average power was 58,426 MW.

Table 38. Power supply and demand in South Korea (unit: MW)

	2007	2008	2009	2010	2011	2012	2013
Installed capacity	67,196	70,353	73,470	76,078	76,649	81,806	86,969
Supply capacity	66,778	68,519	72,071	75,747	77,179	79,972	75,937
Backup power	4,493	5,725	5,274	4,439	4,042	3,985	5,611
Maximum electric power	62,285	62,794	66,797	71,308	73,137	75,987	70,326
Average power	46,019	48,082	49,498	54,185	56,723	58,012	58,426

Source: KEPCO (2014b)

Looking at the generation capacity by resource, the total generation capacity has increased since 2007 in South Korea. The generation capacity of hydro power also has increased from 5,492 MW in 2007 to 6,456 MW in 2013. The generation capacity from anthracite in 2013 remained the same since 2007 at a value of 1,125 MW. The generation capacities of bituminous

[25] bbl: Barrel. The unit of oil volume. 1bbl=158.9 L

coal and combined power have steadily increased, that of crude petroleum has fluctuated, and that of LNG and internal-combustion have decreased. The capacity of nuclear power has increased to 20,716 MW as of 2013. The data of renewable energy generation capacity has only been collected since 2012. The capacity of renewable energy sources covered 3,519 MW in 2013.

Table 39. Generation capacity by resource in South Korea (unit: MW)

Source		*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Hydro		5,492	5,505	5,515	5,525	6,418	6,446	6,454
Steam power	Anthracite	1,125	1,125	1,125	1,125	1,125	1,125	1,125
	Bituminous coal	19,340	22,580	23,080	23,080	23,080	23,409	23,409
	Crude petroleum	5,732	6,677	7,225	8,294	8,960	6,718	7,056
	LNG	1,538	1,538	888	888	888	888	888
	Total	27,734	31,919	32,317	33,386	34,053	32,139	32,477
Combined[26]		17,023	17,044	17,575	19,100	19,799	19,799	23,473
Internal-combustion[27]		303	307	347	351	355	367	330
Nuclear		17,716	17,716	17,716	17,716	18,716	20,716	20,716
Renewable energy		-	-	-	-	-	2,338	3,519
Gross Total		68,268	72,491	73,470	76,078	79,342	81,806	86,969

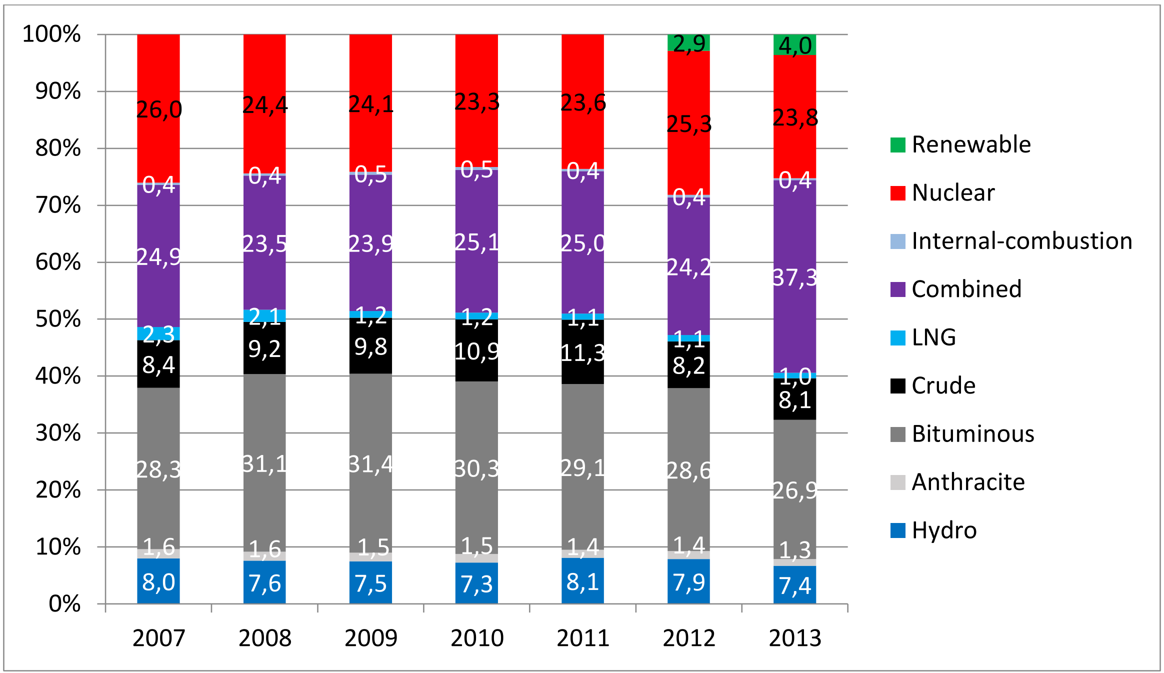
Source: KEPCO (2014b)

Looking at the share of electricity generation capacity by sources, the percentage of the renewable energy generation reached 2.9 percent in 2012, showing a increase by 4 percent in the following year. Hydro power took account for 7.3 to 8.1 percent between 2007 and 2013. The average percentage rates of anthracite, bituminous, crude petroleum, and LNG between 2007 and 2013 were 1.47, 29.38, 9.41, and 1.43, respectively. During the last seven years, the average percentages of combined power, internal combustion, and nuclear were 26.27, 0.43, and 24.36, respectively.

[26] Combined power generation: Combined power generation is the generation combined with gas-turbine generation and thermal (steamed-turbine) generation.

[27] Internal combustion power generation: The internal combustion power was generated by internal combustion engine such as diesel engine or gas turbine. It belongs to thermal power generation in broaden meaning.

Figure 24. Component ratio of electricity generation capacity by resource in 2013

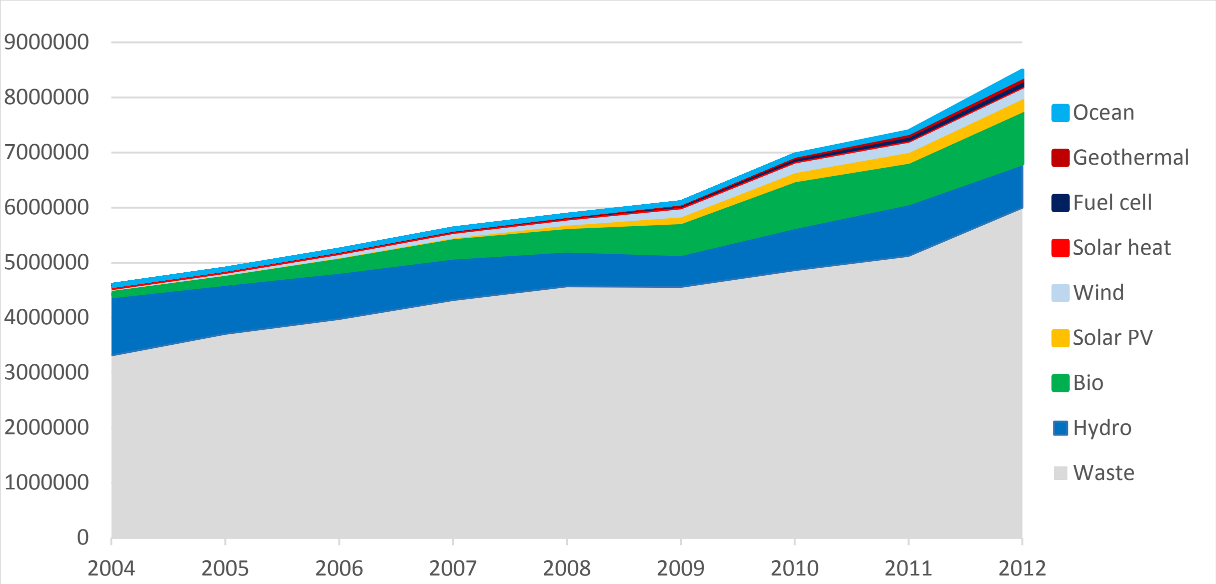


Source: own-figure based on KEPCO (2014b)

New and renewable energy production trend in South Korea

In this section, South Korean new and renewable energy production will be analyzed with respect to total trend, shares of energy sources, solar PV- and heat trend, and trend by region. In contrast to China and Japan, South Korea includes waste as a renewable energy source in terms of renewable energy production. Using waste as a resource has been the most important source for electricity generation among new and renewable energies in South Korea. In 2012, 5,998,509 toe of waste were used for energy production in South Korea. Traditionally, hydro power has been the second largest renewable energy production in South Korea, except in the year of 2012. Bio energy summed up to 963,363 toe whereas hydro power generated 814,933 toe in 2012. Solar PV and Solar heat generated 237,543 and 26,259 toe in 2012. Wind power and geothermal power accounted for 192,674 and 65,277 toe. Data for fuel cell-generated energy has been collected since 2005 and it presented 82,510 toe in 2012. The tendency of geothermal energy production also shows an increase, recording 65,277 toe in 2012. The statistics of ocean energy production has been collected since 2010 and the production reached 98,310 toe in 2012. It can be confirmed that the total quantity of new and renewable energy production in South Korea has exceedingly increased since 2005, except hydro power and solar heat.

Table 40. New and renewable energy production by year in South Korea (toe)

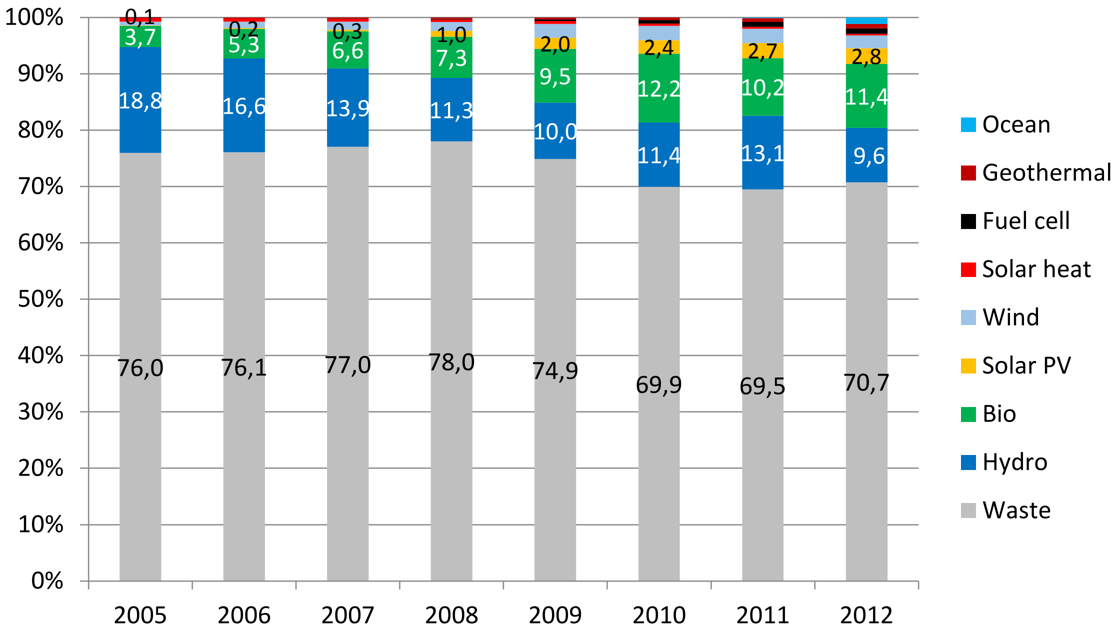


Sources	2005	2006	2007	2008	2009	2010	2011	2012
Ocean	-	-	-	-	-	223	11,246	98,310
Geothermal	2,558	6,208	11,114	15,726	22,126	33,449	47,833	65,277
Fuel cell	526	1,670	1,832	4,367	19,193	42,346	63,344	82,510
Solar heat	34,729	33,018	29,375	28,036	30,669	29,257	27,435	26,259
Wind	32,472	59,728	80,763	93,747	147,351	175,644	185,520	192,674
Solar PV	**3,600**	**7,756**	**15,325**	**61,128**	**121,731**	**166,152**	**197,198**	**237,543**
Bio	181,275	274,482	370,159	426,760	580,419	850,419	754,624	963,363
Hydro	918,504	867,058	780,899	660,148	606,629	792,294	965,373	814,933
Waste	3,705,547	3,975,272	4,319,309	4,568,568	4,558,131	4,862,296	5,121,534	5,998,509
Total	4,879,211	5,225,192	5,608,776	5,858,480	6,086,249	6,952,080	7,374,107	8,479,378

Source: KEMCO (2013)

Among new and renewable energy production in South Korea, waste takes up the majority with 70.7 percent in 2012. The trend of hydro power has been going down since 2005, reaching a level of 9.6 percent in 2012. On the other hand, bio energy, solar PV, and wind power products were growing, amounting to 11.4, 2,8, and 2,3 percent in 2012, respectively. The share of solar heat is decreasing, recording 0.3 percent in 2012 while fuel cells and geothermal energy are increasing, with a share of 0.97 and 0.8 percent in 2012. Ocean energy covered 1.16 percent of new and renewable energy use in 2012.

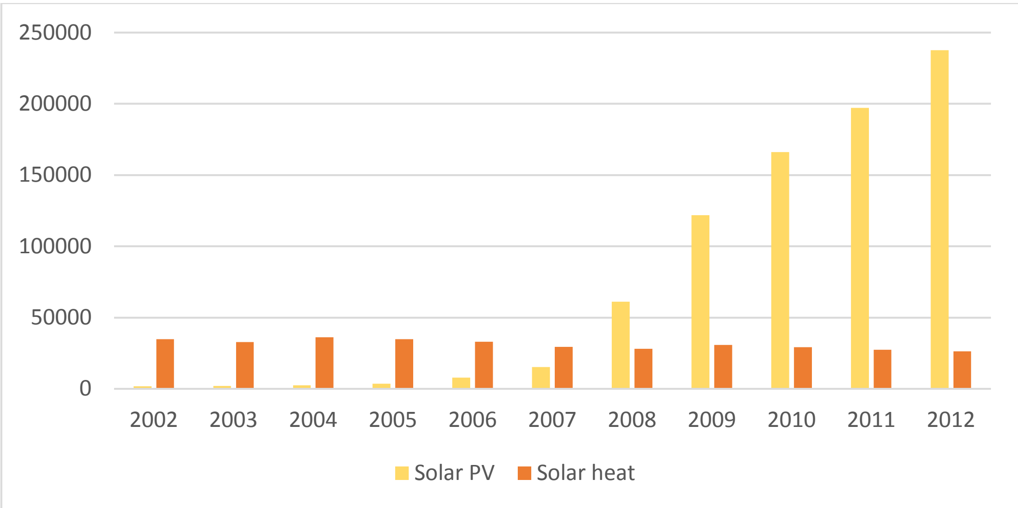
Figure 25. The share of new and renewable energy production in South Korea (2005-2012)



Source: own-figure based on KEMCO (2013)

Looking at the solar energy production in South Korea, solar PV is developing rapidly. There was a more than 134-fold increase in the use of solar PV between 2002 and 2012. The solar PV production has increased from 1,761 toe in 2002 to 237,543 toe in 2012. On the other hand, the quantity of solar heat energy production has lost market share, decreasing between 2002 and 2012. While 34,777 toe of solar heat were produced in 2002, the value fell to 26,259 toe in 2012.

Table 41. Solar energy production in South Korea (unit: toe)



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Solar PV	1,761	1,938	2,468	3,600	7,756	15,325	61,128	121,731	166,152	197,198	237,543
Solar heat	34,777	32,914	36,143	34,729	33,018	29,375	28,036	30,669	29,257	27,435	26,259

Source: KEMCO (2013)

Further refining the analysis by province and metropolitan cities in South Korea, Gyeonggi produced the largest amount of solar thermal production with 3,559 toe in 2012. Gyeongnam, Gangwon, Gyeongbuk, and Chungnam produced solar thermal energy at a value of 3,268, 3,185, 2,552, and 2,553 toe, respectively, in 2012. Solar PV energy production is concentrated in Jeonnam, recording 298,001 MWh in 2012. Gyeongbuk produced 201,832 MWh of solar PV energy, Jeonbuk provided 177,234 MWh, and Gyeongnam made 100,234 MWh in 2012. The solar PV energy production quantity is still less than hydro power, but more than wind power, fuel cell, and ocean energy (KEMCO, 2013).

Table 42. New and renewable energy production by region in South Korea in 2012

	Solar thermal (toe)	**Solar PV (MWh)**	Wind power (MWh)	Hydro (MWh)	Bio gas (toe)	Fuel cell (MWh)	Waste gas (thousand ton of steam)	Geothermal (toe)	Ocean (MWh)
Seoul	1,109	25,710	177	-	30,159	29,632	-	5,132	-
Busan	1,050	11,985	421	27	4,528	53,261	17	974	-
Daegu	1,427	10,948	12	8,781	5,934	75,278	2	1,803	-
Incheon	854	14,874	31,629	24,856	3,612	14,163	413	1,588	-
Gwangju	706	18,012	2	2,025	3,573	2,347	-	1,914	-
Daejeon	816	7,821	350	-	3,661	154	-	1,448	-
Ulsan	372	7407	12	1,965	5,192	391	5,253	662	-
Gyeonggi	**3,559**	53,997	6,156	797,900	18,089	77,523	143	16,071	465,924
Gangwon	3,185	39,008	354,347	857,193	1,888	241	-	5,877	-
Chungbuk	1,151	44,365	14	1,037,100	2,027	21	47	2,980	-
Chungnam	2,553	77,763	22	89,820	12,932	21,743	12,592	5,576	-
Jeonbuk	1,206	177,234	11,818	348,728	3,887	17,113	126	5,830	-
Jeonnam	1,991	**298,001**	8,377	123,289	771	79,679	23,720	6,000	-
Gyeongbuk	2,554	201,832	288,186	262,913	3,158	18,061	13,330	3,700	-
Gyeongnam	3,268	100,234	7,408	307,049	4,519	58	-	5,129	-
Jeju	456	14,035	200,237	442	501	-	-	594	-
Total	26,259	1,103,227	912,760	3,862,087	107,430	389,664	55,643	65,277	465,924

Source: KEMCO (2013)

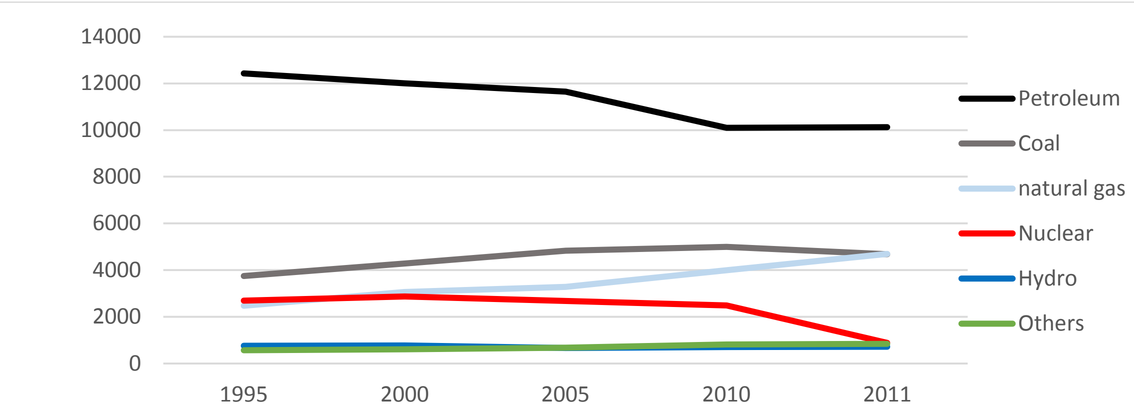
2.4.2.4. Demand, supply and trends in Japan

First, the energy supply, consumption, and consumption rate by fuel type in Japan will be presented in this part. It is completed by showing the imports and exports of energy sources, and the electricity balance as well as the new and renewable electricity generation.

Energy supply, consumption, and rate by fuel type in Japan

Around fifteen percent of domestic energy production can be supplied by resources within the country of Japan (EIA, 2014d). Petroleum has been the most important source of energy since 1995, even though the quantity of supplying petroleum is decreasing. 10,126 petajoules of petroleum were provided in 2011. Following petroleum is coal: 4,687 petajoules were supplied in 2011. The supply of natural gas has steadily increased presenting 4,696 petajoules in 2011. The quantity of supplied natural gas in 2011 doubled in comparison to 1995. The nuclear power supply has dramatically decreased since the Fukushima nuclear disaster in 2011. While the quantity of supplied nuclear power reached by 2,873 petajoules in 2000, the value fell to 885 petajoules in 2011. The supply of others energy sources is of minor relevance, showing a gradual increase to 842 petajoules in 2011.

Table 43. Trends in total primary energy supply in Japan (unit: petajoules)

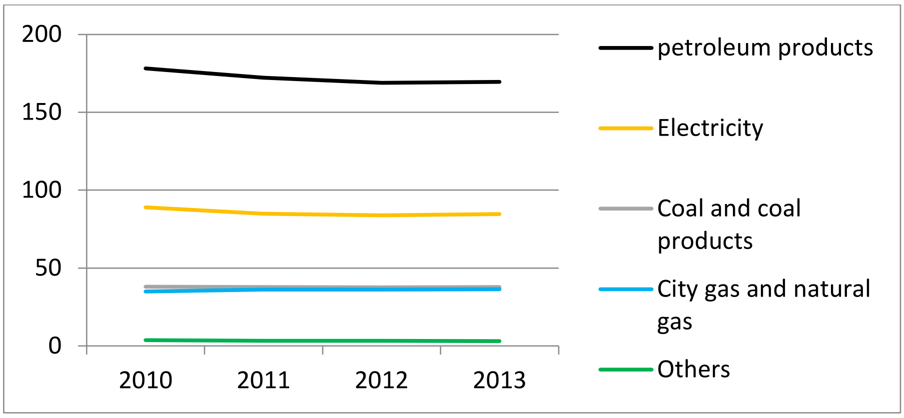


Source	1995	2000	2005	2010	2011
Petroleum	12,430	12,008	11,641	10,101	10,126
Coal	3,750	4,286	4,829	4,997	4,687
Natural gas	2,479	3,061	3,288	4,002	4,696
Nuclear	2,700	2,873	2,677	2,495	885
Hydro	761	778	672	712	724
Others	564	616	676	817	842
Total	24,679	25,622	25,788	25,134	23,971

Source: MIC – Ministry of Internal affairs, and Communications (2013)

In Japan, the total energy consumption fell slightly between 2010 and 2012, except for the use of city gas and natural gas. Overall, petroleum products have been consumed most widely among all energy sources between 2010 and 2012. More specifically, 168.8 Mtoe of petroleum products were consumed in 2012. The consumption of electricity with 83.9 Mtoe followed that of petroleum products. The consumption of coal and coal products, city gas and natural gas, and others showed 37.7, 36.3, and 3.3 Mtoe, respectively. Yanagisawa et al. (2013) expected an increase of 0.5 percent of final energy consumption in Japan in 2013, compared to 2012 (see below).

Table 44. Final energy consumption in Japan (unit: Mtoe)

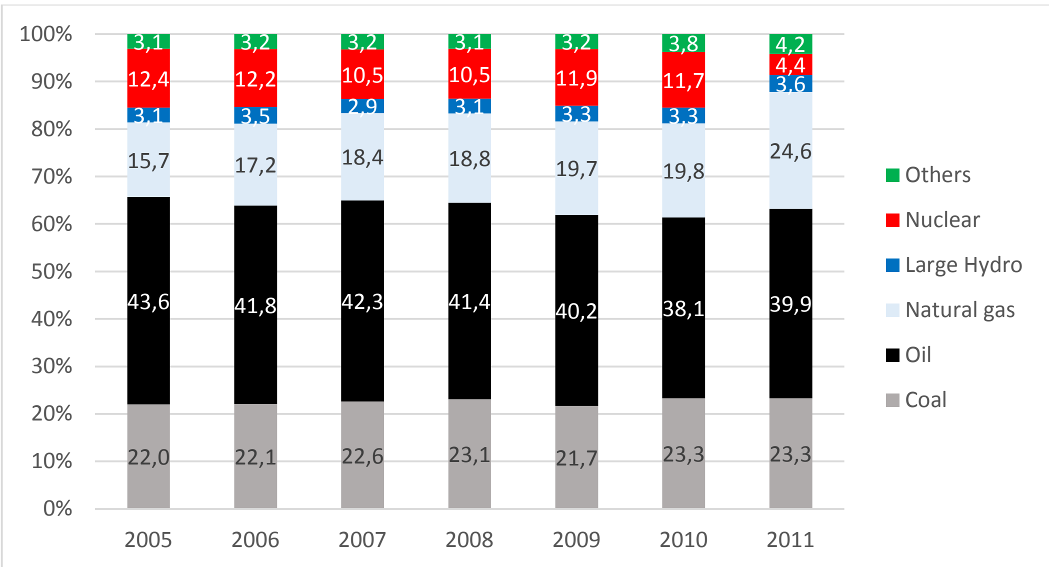


	2010	*2011*	*2012*	*2013 (Projection)*
Coal and coal products	38.0	37.8	37.7	37.8
Petroleum products	178.1	172.1	168.8	169.4
City gas and natural gas	35.0	36.3	36.3	36.5
Electricity	88.9	84.8	83.9	84.6
Others	3.7	3.4	3.3	3.2
Total	343.7	334.4	330.0	331.5

Source: Yanagisawa et al. (2013)

Looking at the shares of primary energy supply, oil has the largest share in Japan. While the nation relied on oil energy supply to more than 70 percent in 1975, the supply fell to 39.9 percent in 2011. Coal, natural gas, and large hydro power covered 23.3, 24.6, and 3.6 percent in 2011. The supply of natural gas has seen a tendency of increase since 2005. The share of nuclear energy supply sharply decreased after 2010, presented 4.4 percent in 2011. The remaining 4.2 percent were covered by other energy supplies.

Figure 26. The share of primary energy supply in Japan 2005-2011



Source: own-figure based on Japan statistical yearbook (2014)

Energy import and export in Japan

Japan is the world's largest importer of LNG, the second largest of coal, and the third largest of crude oil. The total quantity of imported petroleum products has constantly increased since 2009. 1.43 billion barrels per day of refined petroleum were imported in 2012, whereas in 2009, 1.21 billion barrels per day were shipped to Japan. The amount of imported natural gas shows 4,295 billion cubic feet in 2012, and shows a constant increase. The amount of imported coal had fluctuated between 2008 and 2012 (EIA, 2014c).

Table 45. Energy imports in Japan

		2008	2009	2010	2011	2012
Refined petroleum (Thousand Barrels per day)	Motor gasoline	9.85	15.23	18.96	44.05	48.27
	Jet fuel	4.07	15.28	3.04	18.70	21.34
	Kerosene	4.72	6.41	11.27	24.05	20.55
	Distillate fuel oil	5.99	5.44	12.67	15.29	12.23
	Residual fuel oil	86.01	39.40	51.52	94.95	142.76
	Liquefied petroleum gases	669.27	636.21	646.45	649.90	672.59
	Other products	510.11	491.46	564.39	542.70	511.87
Total		1,290.32	1,209.43	1,308.30	1,389.65	1,429.61
Natural gas (Billion cubic feet)		3,369	3,281	3,489	4,113	4,295
Coal (Thousand short tons)		205,919	182,089	206,701	194,071	203,469
Electricity (Billion kilowatt-hours)		0	0	0	0	0

Source: EIA (2014c)

The exports of petroleum products have steadily decreased since 2008. A total of 254.44 million barrels per day were exported in 2012, whereas in 2008, 381.63 barrels per day were exported. There is no natural gas export in Japan and the quantity of exported coal fluctuated between 2008 and 2012. 1.63 million short tons of coal were exported in 2012.

Table 46. Energy exports in Japan

		2008	2009	2010	2011	2012
Refined petroleum (Thousand Barrels per day)	Motor gasoline	13.00	17.48	39.10	27.76	14.92
	Jet fuel	61.68	48.75	39.39	46.19	48.88
	Kerosene	8.99	5.96	3.73	10.33	2.49
	Distillate fuel oil	220.46	215.67	197.39	159.95	120.44
	Residual fuel oil	53.86	55.72	44.25	48.77	43.84
	Liquefied petroleum gases	4.50	5.69	6.20	3.37	6.31
	Other products	19.13	17.49	16.43	16.73	17.57
Total		381.63	366.76	346.48	313.10	254.44
Natural gas (Billion cubic feet)		0	0	0	0	0
Coal (Thousand short tons)		1,044	1,033	723	1,081	1,630
Electricity (Billion kilowatthours)		0	0	0	0	0

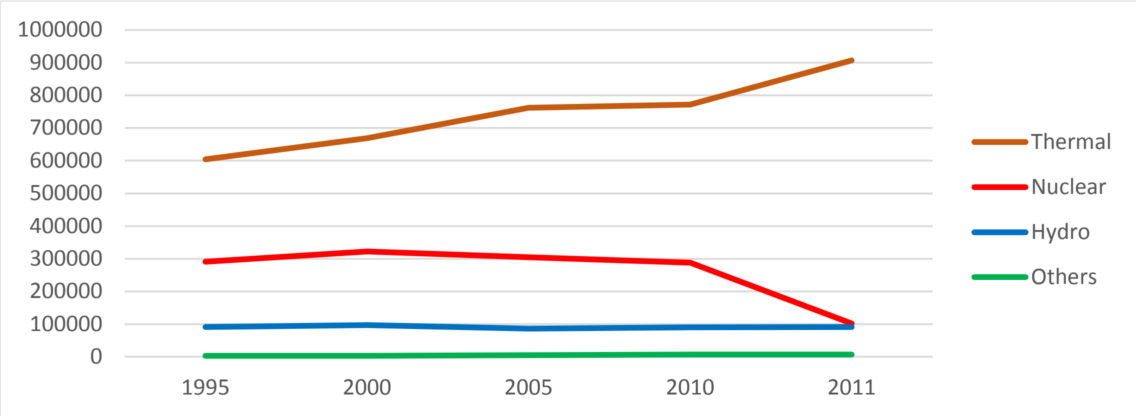
Source: EIA (2014c)

Electricity balance in Japan

The trend of electricity consumption changed significantly just after the Fukushima accident in 2011. The electricity output of thermal power plants has strongly increased since

2010, whereas the output of nuclear power plants sharply decreased. While in 2010, Japan consumed 288.23 billion kWh of nuclear electricity, the quantity of nuclear electricity fell to almost a half only one year later, recording a value of 101.76 billion kWh in 2011. In contrast, 906.95 billion kWh of thermal electricity were consumed in 2011. In addition, Japan relies on hydroelectricity which remained quite stable in terms of output and power consumption. 91.22 billion kWh were consumed in 1995, and 91.71 in 2011. Other electricity sources have gradually increased, but the data sets do not indicate the composition of this figure. It can be assumed that renewable energies are among them. The electricity output in this category was 7.41 billion kWh in 2011.

Table 47. Trends in Electricity output and power consumption in Japan (Unit: Million kWh)

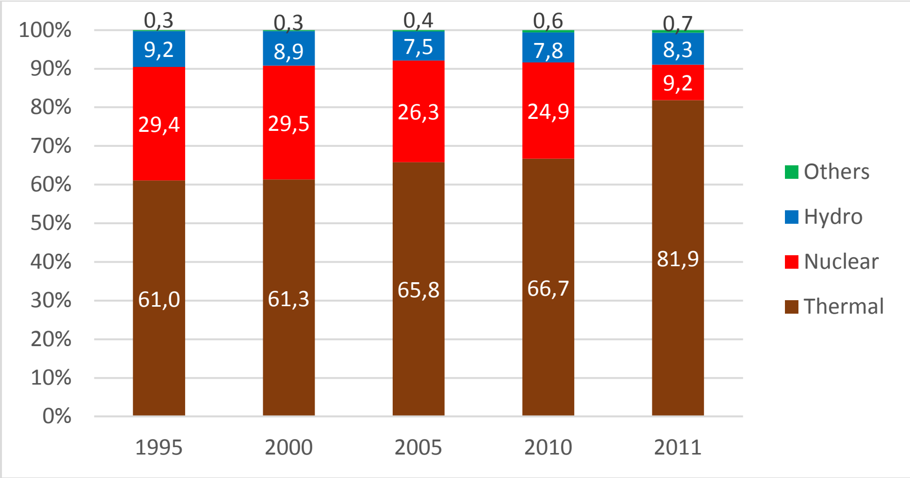


Source	1995	2000	2005	2010	2011
Thermal	604,206	669,177	761,841	771,306	906,946
Nuclear	291,254	322,050	304,755	288,230	101,761
Hydro	91,216	96,817	86,350	90,681	91,709
Others	3,204	3,456	4,980	6,671	7,413
Total	989,880	1,091,500	1,157,926	1,156,888	1,107,829

Source: MIC (2013)

Shown as a percentage of electricity output by source, we can see the same development: The trend changed visibly after 2010, when the share of nuclear electricity output decreased strongly from 24.9 percent in 2010 to 9.2 percent in 2011. On the other hand, the share of thermal electricity output has increased to 81.9 percent in 2011. The share of hydro power and other sources of electricity production covered 8.3 and 0.7 percent in 2011, respectively. The tendency of the latter has shown an increase since 1995.

Figure 27. The percentage of electricity output by source in Japan

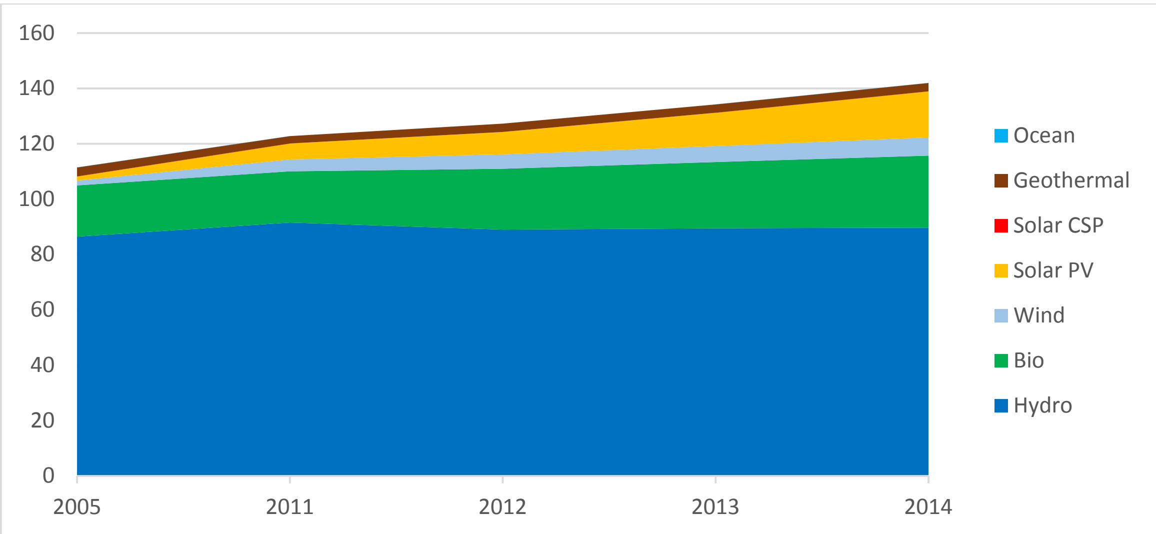


Source: own-figure based on MIC (2013)

Renewable electricity generation trend and solar PV installation in Japan

Among renewable electricity generation sources, hydro power was the most widely used renewable energy in Japan in 2013. 89.4 TWh of hydro power was generated, a figure that remained stable since 2005. The bio energy sources produced 24 TWh, and wind power provided 5.8 TWh in 2013. The development of Solar PV electricity generation was remarkable in Japan: it shows the strongest increase in comparison to the other renewable energy sources. The electricity generation of solar PV in 2013 reached 12 TWh, which is about 12 times the value of 2005. Geothermal energy accounted for 3.0 TWh in 2013, a slightly reduced amount in comparison to 2005.

Table 48. Renewable electricity generation in Japan (TWh)

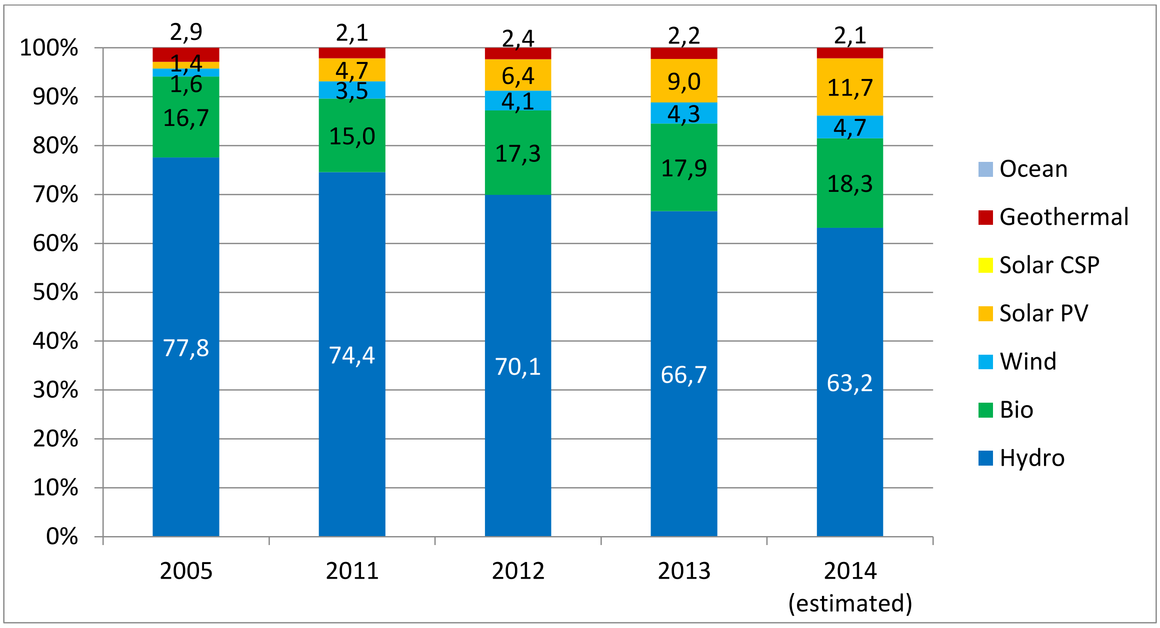


Sources	2005	2011	2012	2013	2014 (estimated)
Ocean	-	-	-	-	-
Geothermal	3.2	2.6	3.0	3.0	3.0
Solar CSP	**-**	**-**	**-**	**-**	**-**
Solar PV	**1.5**	**5.8**	**8.1**	**12.0**	**16.6**
Wind	1.8	4.3	5.2	5.8	6.6
Bio	18.5	18.5	22.0	24.0	26.0
Hydro	86.4	91.5	89.0	89.4	89.7
Total	111	123	127	134	142

Source: IEA (2012b:34)

Looking at the below figure, the share of hydro power generation has been decreasing whereas bio energy, wind power, and solar PV show increasing values. In 2013, hydro power, bio energy, wind power, and solar PV electricity generation accounted for 66.7, 17.9, 4.3, and 9.0 percent, respectively. Geothermal power made up 2.2 percent in 2013. There are no statistics of the solar CSP and ocean power so far.

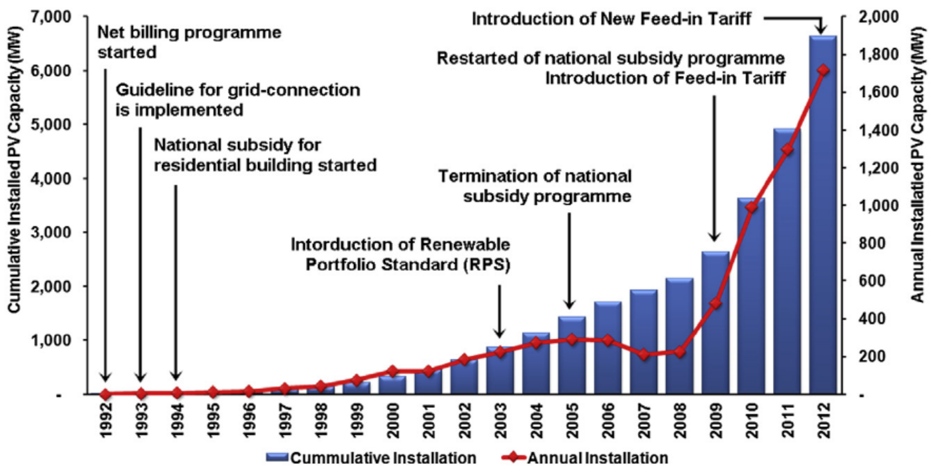
Figure 28. The share of renewable electricity generation in Japan



Source: IEA (2012b), own-figure

The amount of solar PV installations in Japan has been steadily developed since 1992. The trend in annual installations of solar PV technology shows an increase except between 2006 and 2008. The annual solar PV installations reach almost 1,800 MW in 2012. The cumulative installed PV capacity is around 6,500 MW as of 2012.

Figure 29. The progress of solar PV installations in Japan (1992-2011)



Source: Muhammad-Sukki et al. (2014:638)

2.4.3. Energy Prices

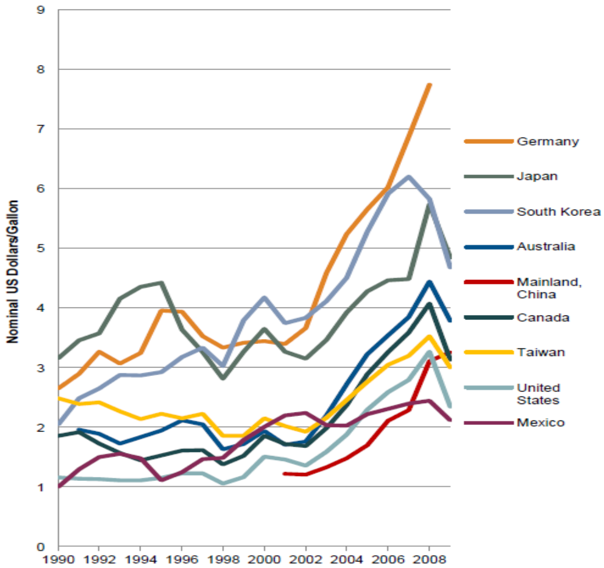
This chapter examines the trend of conventional energy prices, in comparison to the price of solar energy and other renewable energies. The price of electricity will also be indicated, as it relates with solar energy. For example, the electricity fee is a certain percentage of polysilicon production cost (Kim JY, 2014). Concluding this chapter, the solar energy costs and prices will be explored by country.

2.4.3.1. Energy and electricity prices in China

1. **Gasoline:** Gasoline prices were available through LBNL index, showing the development from 1990 to 2008 in the graph below. The indicated Chinese price (red line) level of 3.3 US dollars per gallon (about 0.87 US dollars per liter) in 2008 (LBNL, 2012) shows on the one hand a strong rise of Gasoline Prices within mainland China, but in relation to many other countries including South Korea and Japan, it is still much lower. Current gasoline prices are lower again – 1.31 US dollars[28] per liter in the third quarter of 2013, and 1.25 US dollars per liter as of the second quarter of 2014 (BesTan, 2014; Bloomberg, 2014).

[28] 1 US Dollars=1,062.4 (as of 1st, Oct 2014)

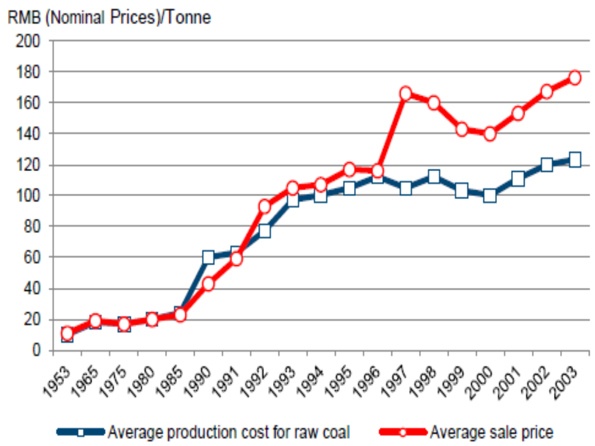
Figure 30. Retail gasoline price (including tax) in selected countries from 1990 to 2008



Source: LBNL– Lawrence Berkeley National Laboratory (2012: 31)

2. Coal: The coal price index was available for the years 1953 – 2003, showing a strong upwards movement. Coal was sold at cost price until 1985, then showing an average for the following six years, until Chinese production companies started to earn revenues, especially since 1996 when the sales price surged in comparison to the average production costs. Looking at current prices, they seemed to have remained stable since the sales price of coal from state-owned coal mines in China was about 180 RMB/Tonne in 2003, while the average production cost was approximately 120 RMB per Tonne (LBNL, 2012). The coking coal price was 162.23 US dollars per metric Tonne as of March 2014, while it was 176.64 US dollars per metric Tonne in 2013 (Xun, 2014).

Figure 31. Production cost and average sale price of state-owned coal mines in China (1953-2003)



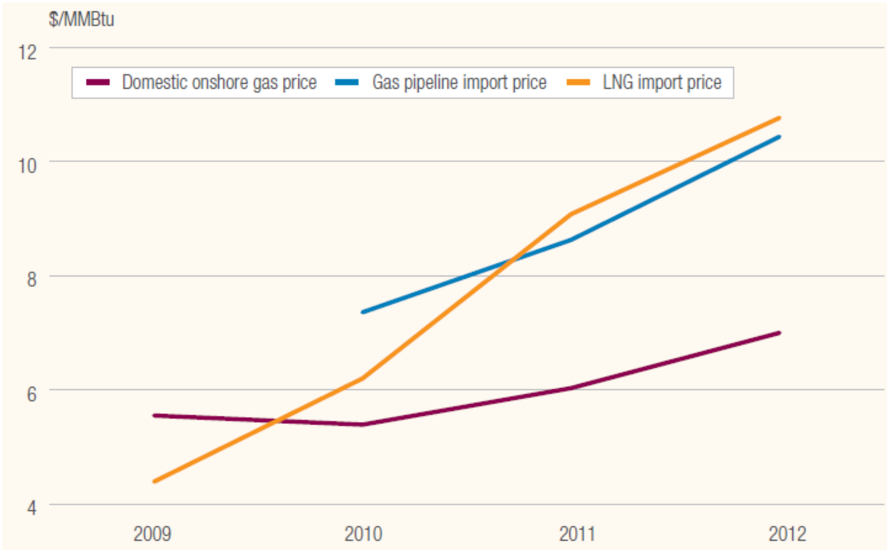
Source: LBNL– Lawrence Berkeley National Laboratory (2012: 27)

3. Gas: The gas price has seen a steady increase in China since 2009. The residential natural gas prices in Guangxi, Guangdong, Jiangxi, Fujian, and Yunnan in 2011 were about 4.8, 3.7, 3.6, 3.6, and 3.6 RMB per cubic meter, respectively. The cheapest residential natural gas prices in China were about 1.5, 1.5, 1.5, 1.4, and 1.3 RMB per cubic meter in Sichuan, Gansu, Ningxia, Chongqing, and Qinghai, respectively.

The commercial gas prices in Nanning, Xiamen, Shenyang, Haikou, and Shanghai were 5.73, 4.2, 3.90, 3.73, and 3.69 RMB per m^3 in 2011. The price in Chengdu, Lanzhou, Urumqi, Xining, and Yichuang were 2.20, 2.17, 2.11, 2.07, and 1.98 RMB per m^3. The industrial gas prices in Nanning, Shenyang, Xiamen, Jinan, and Qingdao were 4.60, 3.90, 3.81, 3.61, and 3.61 RMB per m^3 in 2011 while that of Urumqi, Hohhot, Lanzhou, Xining, and Yichuang were 2.11, 2.00, 1.90, 1.70, and 1.38 RMB per m^3 in 2011 (LBNL, 2012). The domestic onshore gas price was about 7 US dollars per MMBtu[29] in 2012 (Song, 2013).

[29] Btu=British thermal unit, MMBtu is 2,000 Btu

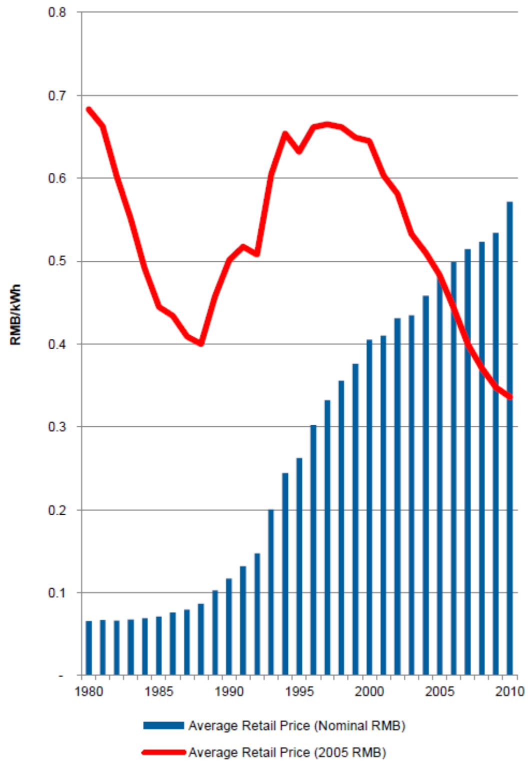
Figure 32. China's average gas prices (2009-2012)



Source: Song (2013)

4. Electricity: The average retail price of electricity (Nominal RMB) in China has also been strongly increasing since 1980. The nominal price almost reached 0.6 RMB per kWh in 2010, while it was less than 0.1 RMB per kWh in 1980's. Looking at differences by province, the average residential power price is highest in Guangdong province showing 0.37 RMB/kWh in 2010. The electricity prices in Hainan, Jiangxi, and Hubei were 0.35, 0.35, and 0.33 RMB per kWh, respectively, in 2010. On the other hand, the prices in Qinghai, Inner Mongolia (west), Guizhou were 0.21, 0.22, 0.26 RMB per kWh, respectively (LBNL, 2012). The price was between 0.46 RMB per kWh and 0.66 RMB per kWh as of 2012 (Energy use calculator, 2014). Regarding prices of renewable energies, there are no data available indicating any Chinese market prices for renewable energy sources.

Figure 33. Average retail price of electricity in China (1980-2010)



Source: LBNL (2012: 28)

2.4.3.2. Energy and electricity prices in South Korea

The energy prices in South Korea increased strongly since 1993. The prices of gasoline, kerosene, and diesel were 1,985.8, 1,394.1, and 1,806.3 won per liter in 2012. The propane price for general purposes was 2,105.9 won/m^3 in 2012 and the propane town gas price was at a level of 4,203.7 won/m^3 in 2011. The butane price for home and industry purposes was 1,572.5 won/kg and that for transportation purposes was 1,101.9 won/l. The anthracite coal and briquette cost 142,230 won/ton and 391 won/piece. The town gas prices for homes, for commercial purposes, and for the industry were 848, 891, and 794 won/m^3, respectively.

Table 49. Price by energy type in South Korea

Sources		1993	1995	2000	2005	2010	2011	2012
Oil	Gasoline(Won[30]/L)	610.0	598.0	1,248.5	1,432.3	1,710.4	1,929.3	1,985.8
	Kerosene(Won/L)	254.0	261.6	545.0	873.7	1,076.0	1,321.2	1,394.1
	Diesel(Won/L)	210.0	231.5	612.9	1,079.7	1,502.8	1,745.7	1,806.3
Propane	General purpose(Won/kg)	460.0	489.7	809.3	1,131.5	1,812.7	2,034.0	2,105.9
	Town gas[31](Won/m^3)	185.9	196.6	1,682.0	2,366.4	3,746.4	4,203.7	-
Butane	Home & Industry purpose(Won/kg)	304.0	314.9	614.3	807.1	1,320.3	1,480.4	1,572.5
	Transportation purpose(Won/L)	-	-	358.7	723.4	952.2	1,076.1	1,101.9
Coal	Anthracite(Won/ton)	40,740	40,740	62,210	76,197	123,680	131,456	142,230
	Briquette(Won/piece)	185	185	185	202	391	391	391
Electricity	Low pressure (for light) (Won/kWh)	81	85	97	90	96	98	105
	High pressure (for power) (Won/kWh)	54	52	66	68	83	86	97
Town gas	Home(Won/m^3)	295.5	297.2	461.3	485.6	716.6	783.9	848.0
	Commercial(Won/m^3)	230.4	236.0	406.0	502.6	758.2	837.7	891.0
	Industrial(Won/m^3)	194.0	196.7	291.8	396.1	661.8	724.5	794.4

KEMCO (2014a)

The average electricity settlement unit payment has also increased since 2007, but not as strong, and even showed signs of a decrease in 2013. Nuclear power has been the cheapest source of energy among all energy sources, at a price of 39.0 won per kWh in 2013. The settlements of bituminous and anthracite were at 58.8 and 91.6 won/kWh. The fees for LNG and Oil were 160.8 and 221.7 won/kWh. The unit prices for pumping energy and hydro energy

[30] 1 US dollar=1,022.00 Korean won as of 5th ,June 2014
[31] Town gas = Town gas is the fuel gas that central supplier in the town supplies to each consumer through pipes. These days LNG is the most common town gas.

were at a level of 204.2 and 170.8 won/kWh. The average electricity settlement unit payment was 87.8 won/kWh in 2013.

Table 50. Electricity settlement unit payment[32] by fuel type in South Korea (unit: won/kWh)

	2007	2008	2009	2010	2011	2012	2013
Nuclear	39.4	39.0	35.6	39.6	39.1	39.5	39.0
Bituminous	40.9	51.2	60.2	60.8	67.1	66.2	58.8
Anthracite	65.4	117.5	109.1	110.0	98.6	103.8	91.6
LNG	104.9	143.7	129.5	128.1	142.4	168.1	160.8
Oil	118.3	194.4	147.2	184.6	225.8	253.0	221.7
Pumping	163.3	196.8	149.7	202.6	168.8	213.9	204.2
Hydro	94.5	135.7	110.5	135.3	136.1	180.9	170.8
Average	56.5	68.3	66.3	71.1	79.5	90.2	87.8

Source: KPX-Korea Power Exchange (2014)

Similar to the general rise in electricity costs, solar energy generating costs in South Korea are moving upward. Even though the costs decreased to 103.73 won per kWh in 2009, they started to increase again in the following year, reaching 185.97 won per kWh in 2014. The trend of the other new and renewable energy generating costs is similar. Overall, among all new and renewable energy sources in South Korea, the generating cost of solar energy has been one of the highest ones.

Table 51. New & renewable energy generating cost[33] (Unit: Won/kWh)

	2008	2009	2010	2011	2012	2013	2014
Bio gas	127.33	98.75	116.09	125.11	158.66	157.76	174.25
Hydro	115.59	93.99	115.28	123.21	156.60	150.03	152.13
Landfill gas	121.28	104.17	115.09	124.37	157.40	151.09	151.12
Solar	**136.88**	**103.73**	**124.93**	**130.68**	**170.57**	**171.90**	**185.97**
Waste	122.65	95.67	113.56	123.18	156.30	148.43	152.04
Wind	126.73	107.84	124.35	143.08	174.61	162.75	164.04
Fuel cell	146.88	101.97	114.16	124.47	157.07	156.06	156.85
Ocean	-	126.21	117.60	134.05	154.65	147.30	149.39

Source: EPRC - Electricity industry Policy Research Center (2012); EPSIS (2014)

2.4.3.3. Energy and electricity prices in Japan

Looking at Japan, the trend of energy prices has also been increasing. Among traditional energy sources, the gasoline price in 2013 was 156 yen per liter and the price of kerosene for households was 98,930 yen per 1000 liters. The automotive diesel price for commercial use was 121.9 yen/l and that of for non-commercial use was 135.2 yen/l in 2013. The automotive LPG prices for commercial use and non-commercial use were 78.6 and 83.3 yen/l in 2010. The natural gas prices for industry and households were 6,146 and 13,539 yen per megawatt hour

[32] Settlement unit payment: total settlement amount/Adjusted metered generation output
[33] Electricity market generating cost formula (Won/kWh) = the amount in electricity market/ electricity market volume. Statistics of 2014 is the average amount until April, 2014

GCV[34] in 2012. The price of steam coal for industry was 12,253 yen per ton in 2013. Interestingly, the prices for households are by far more expensive than that for the industry, which was not the case in South Korea.

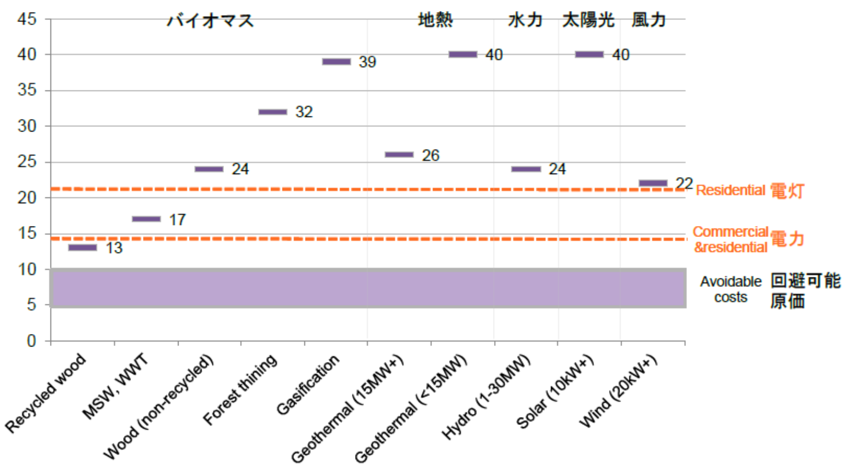
Table 52. Price by energy in Japan

	2003	2006	2009	2010	2011	2012	2013
Regular unleaded gasoline (Yen[35]/L)	106.3	137.5	120.2	132.9	145.8	146.9	156.0
Kerosene for households (Yen/1000L)	47,824	79,566	66,683	76,263	90,508	91,701	98,930
Automotive diesel for commercial use (Yen/L)	65.2	92.7	82.2	94.7	106.9	110.3	121.9
Automotive diesel for non-commercial use (Yen/L)	84.5	113.0	103.5	112.8	126.0	127.2	135.2
Automotive LPG for commercial use (Yen/L)	61.3	71.8	72.2	78.6	-	-	-
Automotive LPG for non-commercial use (Yen/L)	65.1	75.7	77.1	83.3	-	-	-
Natural gas for industry (per megawatt hour GCV)	3,836	4,356	4,549	4,789	5,611	6,146	-
Natural gas for household (per megawatt hour GCV)	11,911	12,395	12,672	12,473	13,201	13,539	-
Steam coal for industry (per ton)	4,179	8,066	11,386	10,610	12,270	12,015	12,253
Electricity for industry (per megawatt hour)	14,091	13,618	14,763	13,550	14,294	15,504	17,004
Electricity for households (per megawatt hour)	21,525	20,726	21,300	20,374	20,833	22,088	23,633

Source: IEA (2014)

Figure 34 below shows the purchase prices and retail prices by source in Japan. The solar energy purchase price is at around 40 Yen per kWh which is the most expensive one among all resources. The residential light price is around 21 yen per kWh and the commercial and residential electricity price is about 14 yen per kWh. The purchase price of wind is the cheapest one among renewable energy sources, except biomass.

Figure 34. Purchase price and retail price by sources and avoidable costs in Japan [36](Yen/kWh)



Source: Nakamura (2013: 6)

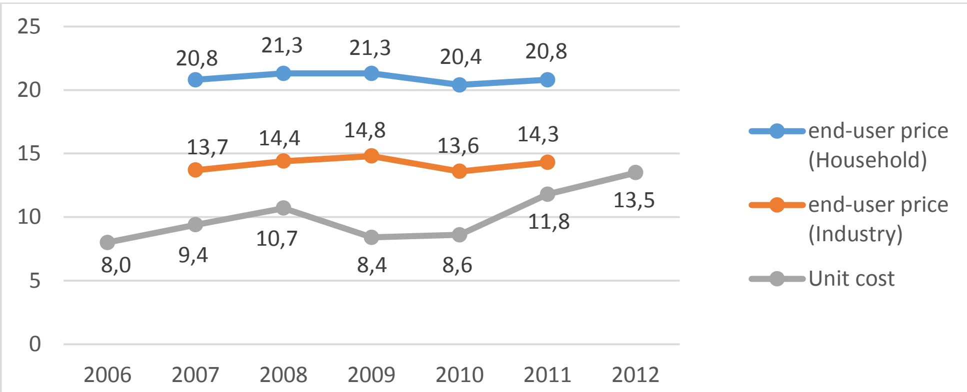
[34] GCV: Gross Calorific Value
[35] 1 US dollar=102.55 Yen as of 5th ,June 2014
[36] Note: Consumption tax excluded. Tariffs apply for 15 years for geothermal, and 20 years for others.

The trend of electricity unit costs is generally increasing in Japan, except for the years 2009-2010. The unit costs of power generation in 2012 were 13.5 yen/kWh. The prices for end-users in both industry and households are comparatively stable. The end-user prices for household and industry were 20.8 and 14.3 yen/kWh in 2011. The prices are the average prices from 12 electric utilities in Japan.

Looking at the Tokyo Electric Power Co, Inc (TEPCO) standard, the electricity price for households is split into three categories: the higher the electricity demand, the higher the price: Up to 120 kWh/month, the price was 18.89 yen/kWh, between 120-300 kWh/month the price rose to 25.19 yen/kWh and at a demand of more than 300 kWh/month, the price was 29.10 yen/kWh in 2012.

Also, electricity is more expensive in summer: The electricity price for commercial use was 16.65 yen/kWh during summer and in other seasons a little lower at 15.55 yen/kWh. For industrial electricity use, the price was 15.34 yen/kWh in summer and 14.37 yen/kWh in other seasons; prices indicated for more than 500 kW high-voltage. Less than 500kW is more expensive: being 16.49 yen/kWh in summer, and 15.41 yen/kWh in other seasons (Yamada and Ikki, 2012).

Figure 35. Trend of average unit cost and end-user price of power generation in Japan (12 Electric utilities) (Unit: Yen/kWh)

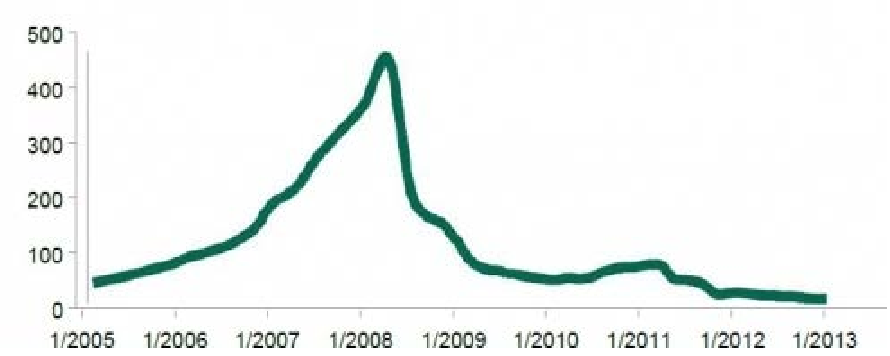


Source: Matsuo and Yamaguchi (2013); IEA (2012c)

2.4.3.4. Prices of solar energy-related products

In this section, the average price of solar energy-related products such as polysilicon, wafer, cell and modules will be explored in order to capture the market situation of raw material suppliers. For example, the price of polysilicon reached a peak in 2008 and fell back to a very low level since then. The average price is 20.70 USD per kg as of October 2014.

Figure 36. Polysilicon price trends (2005- 2013) (unit: USD per kg)



Source: Osborne (2013)

The average prices of 156mm multi wafers, 156mm high-efficiency multi wafers, 156mm mono wafers, and 125mm mono wafers are around one dollar per wafer. More specifically, current prices in October 2014 were: 0.870, 0.990, 1.193, and 0.688 US dollar, respectively.

Table 53. Price of solar PV poly silicon and wafer (as of 8th October 2014)[37]

Price	PV Poly Silicon spot price (unit: USD/kg)		Solar PV wafer spot price (unit: USD)			
	PV Grade[38] poly silicon (9N/9N+)	2nd Grade[39] Poly Silicon (6N-8N)	156mm multi wafer	156mm high efficiency multi wafer	156mm mono wafer	125mm mono wafer
High	23.00	22.80	1.05	1.05	1.32	0.75
Low	19.00	17.80	0.84	0.87	1.15	0.66
Average	20.70	20.60	0.870	0.990	1.193	0.688

Source: PVinsight (2014)

Multi cells are available in the types 156mm multi cell, 156mm mono cell, and 125mm mono cell, the price is indicated per watt and amounts to 0.321, 1.369, 1.905, and 1.144 USD as of October 2014. The average PV module price of a silicon module and of a thin film module is 0.612 and 0.644 USD as of October 2014.

Table 54. Price of solar PV cell and module (as of 8th October 2014)

Price	Solar PV cell spot price (unit: USD)					Solar PV module spot price (USD/watt)	
	Multi cell price per watt	156mm multi cell	156mm mono cell	125mm mono cell	Taiwan poly cell per watt	Silicon module	Thin film module
High	0.44	1.98	2.65	1.61	0.42	0.88	0.84
Low	0.30	1.23	1.66	0.97	0.30	0.52	0.50
Average	0.321	1.369	1.905	1.144	0.324	0.612	0.644

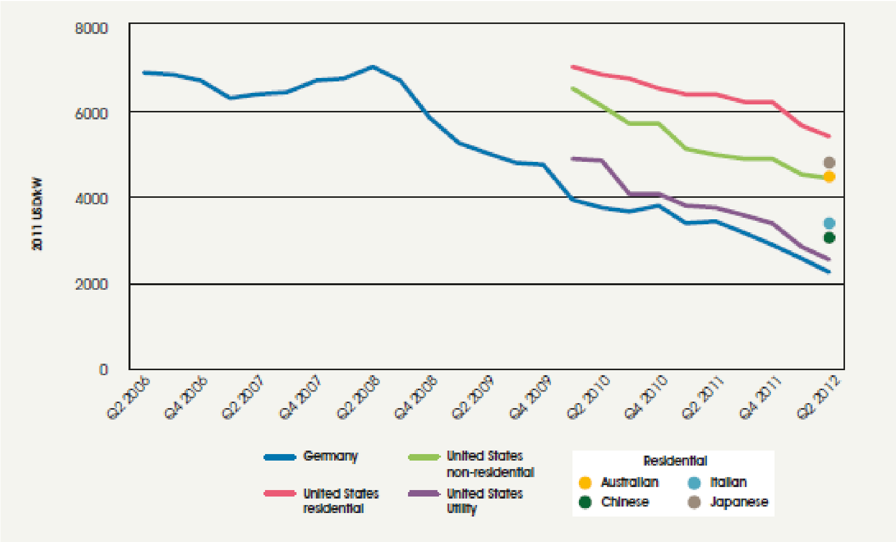
Source: PVinsight (2014)

The solar PV installation costs for both residential and non-residential use have been declining in many countries since 2006. The rooftop-system price for residential in China was

[37] All spot prices are tax excluded. These tables are for information purpose only.
[38] PV Grade: Poly silicon chunk with high purity can be directly produced to solar PV ingots/bricks.
[39] Poly silicon chunk must be mixed with high purity polysilicon, when producing solar PV ingots/bricks.

about 3.1 US dollars per watt and the price in Japan was around 4.8 US dollars per watt in 2012. These costs in China and Japan are generally less than in the United States.

Figure 37. Solar PV system price trends by sector and country (2006-2012)



Source: IRENA (2012:54)

2.4.4. Market Players

In this section, the main players of the East Asian solar energy market are introduced. A brief introduction of each company will be shown including its history, and current figures given such as the number of employees, and the capacity of factories. What is more, the production specifications and financial statements are presented. Comparing the production specifications and financial statements among companies, their potential will be analyzed.

Overall, the Global solar PV market has a capacity of approximately 139 GW in 2013. Out of that, Asia produces about 87 percent, while Europe only accounts for 9 percent and the U.S for 3.6 percent of the share (REN21, 2014). China specifically produces 67 percent of solar PVs in the world (REN21, 2014), and Japan accounts for 5 percent of world solar PV production (REN21, 2014).

2.4.4.1. Chinese companies

China has three main market players in the solar PV market: *Yingli*, established in 1998 and leader of the solar module market in 2013; *Trina Solar*, established in 1997 nowadays holding 575 solar patents; and *Jinko Solar*, founded in 2006, which achieved a vertical integrated solar product value chain. Each of them is introduced below.

Yingli

In 1998, the Yingli Green Energy Holding Company Limited was established in China. According to REN21 report, the largest solar panel manufacturer in the world, Yingli led the solar module market in 2013 (REN21, 2014). 18,000 employees are currently working in 20 offices around the world. In 2007, the company was listed on the New York Stock Exchange (NYSE) with the symbol of YGE. With production facilities in Baoding, Haikou, Tianjin, and Hengshui, the firm has 2.45 GW of solar panel production capacity including ingot, wafer, PV cell and PV modules as of 2013 (Yingli, 2014a). The company had a share of 6.7 percent in the solar PV module manufacturing market in 2013 (REN21, 2013). The average selling price was 0.77 USD per watt in 2012, significantly lower than 1.43 USD per watt in 2011 (Yingli, 2014b). Yingli sells both poly-and mono-crystalline silicon solar module products. Its mono-crystalline silicon shows the highest efficiency among comparable products.

Table 55. Solar module specification of Yingli

	Production name	Maximum power-Pmax (W)	Efficiency	Dimensions (mm)	Weight (kg)	Warranty
Poly-crystalline silicon[40]	YGE 48 Cell Series	190-210	14.7-16.2	1310*990*40	14.7	10-year limited product warranty, 10 years at 91.2 % and 25 years at 80.7 % of the minimal rated power output.
	YGE 60 Cell Series	240-260	14.7-15.9	1650*900*40	18.5	
	YGE 72 Cell Series	290-310	14.9-15.9	1970*990*50	26.0	
Mono-crystalline silicon	Panda 48 Cell Series	205-225	15.6-17.7	1330*990*40	14.9	
	Panda 60 Cell Series	260-280	15.9-17.7	1650*990*40	18.5	

Source: Yingli (2014), own-table

Yingli reached a peak of total net revenues in 2011, recording 14.7 billion RMB; nevertheless, it generally does not operate profitable and recorded its highest net loss in the same year. Operating loss and net loss have continued since 2011, even though the shipment of PV modules has increased since 2009. The volume of PV module shipment rose about six-fold between 2009 (525.3 MW) and 2013 (3,234.3 MW).

Table 56. Financial statements of Yingli

	2009	2010	2011	2012	2013
Total net revenues (thousand RMB)	7,254,869	12,499,987	14,677,965	11,391,928	13,418,093
Operating profit (loss) (thousand RMB)	318,550	2,780,598	(2,695,068)	(2,523,316)	(1,118,382)
Net income (loss) (thousand RMB)	(452,730)	1,698,033	(3,265,777)	(3,191,887)	(2,054,898)
PV modules shipment (in megawatts)	525.3	1,061.6	1,603.8	2,297.1	3,234.3

Source: Yingli (2011; 2014b), own-table

[40] Based on sales in Asia pacific and Middle-East Asia.

Trina Solar

Trina Solar was established in 1997 and was listed on the NYSE (TSL) in 2006. The company owns 575 solar patents, and 13,700 employees were working in over 20 offices around the world in 2013. The annual module capacity reached 2.8 GW in 2013. The efficiency of polycrystalline silicon products shows average between 14.6 percent and 16.0 percent. Among comparable products on the market, the product PDG is sold with a 30 year linear power warranty, while other products (including that of other companies) are normally sold with a 25 year linear power guarantee.

Table 57. Solar module specification of Trina solar

<table>
<tr><th></th><th>Production name</th><th>Maximum power-Pmax (W)</th><th>Efficiency</th><th>Dimensions (mm)</th><th>Weight (kg)</th><th>Warranty</th></tr>
<tr><td rowspan="4">Poly-crystalline silicon</td><td>PDG5</td><td>245-260</td><td>14.6-15.5</td><td>1685*997*6</td><td>24.0</td><td>10 year product warranty, 30 year linear power warranty</td></tr>
<tr><td>PA05</td><td>245-260</td><td>15.0-15.9</td><td>1650*992*35</td><td>18.6</td><td rowspan="5">10 year product warranty, 25 year linear power warranty</td></tr>
<tr><td>PD05</td><td>245-260</td><td>15.0-15.9</td><td>1650*992*35</td><td>18.6</td></tr>
<tr><td>PD14</td><td>295-310</td><td>15.2-16.0</td><td>1956*992*40</td><td>27.6</td></tr>
<tr><td rowspan="2">Mono-crystalline silicon</td><td>DC80.08</td><td>210-215</td><td>16.4-16.8</td><td>1581*809*35</td><td>14.9</td></tr>
<tr><td>DC05A</td><td>260-275</td><td>15.9-16.8</td><td>1650*992*35</td><td>18.6</td></tr>
</table>

Source: Trina solar (2014a), own-table

Similar to Yingli, Trina Solar recorded its highest total net revenues in 2011, obtaining almost 2.05 billion USD. As of the end of 2013, the company earned 1.77 billion USD of total net revenues. On the other hand, the company realized net losses since 2011, and had to bear operating losses in 2012 and 2013. The shipment of PV modules and the average selling price have steadily increased since 2009. The volume of PV modules was 2,584.3 MW in 2013. The average selling prices was 0.64 UDS per watt per watt in 2013 whereas it was 2.10 USD in 2009.

Table 58. Financial statements of Trina Solar

	2009	2010	2011	2012	2013
Total net revenues (Thousand USD)	845,136	1,857,689	2,047,902	1,296,655	1,774,971
Operating profit (loss) (USD)	135,369	417,348	30,966	(264,872)	(38,080)
Net income (loss) (USD)	96,226	311,453	(37,820)	(266,555)	(72,236)
PV modules shipped (in MW)	339.0	1,057.0	1,512.0	1,594.0	2,584.3
Average selling price ($/W)	2.10	1.75	1.33	0.78	0.64

Source: Trina solar (2014b), own-table

Jinko Solar

Jinko Solar Holding Co., Ltd was founded in 2006 and was listed on the NYSE in 2010 with the code JKS. Launching ingot manufacturing in 2007, wafer manufacturing in 2008, and being the first to operate a fully automated PV module NPC production line in China, Jinko Solar has achieved a vertical integrated solar product value chain. The firm had a capacity of

2.0 GW of silicon ingots, wafers, and solar PV cells, and 2.1 GW of solar PV modules in 2013. 13,000 employees are working in 16 countries in worldwide. The factories are located in the Jiangxi and Zhejiang provinces in China. The poly-crystalline silicon of Jinko Solar has an efficiency between 16.6 and 18.0 percent and Mono-crystalline silicon shows an efficiency of 17.9 – 19.4 percent. The company produces two sizes of mono-crystalline silicone cells; 125*125 and 156*156 mm.

Table 59. Solar cell specification of Jinko Solar

	Size (mm)	Conversion efficiency (%)	Thickness (microns)	power output (W)
Poly-crystalline silicon	156*156	16.6-18.0	180±20	4.04-4.38
Mono-crystalline silicon	125*125±0.5	18.0-19.4	180±20	2.79-3.00
	156*156±0.5	17.9-19.3	180±20	4.28-4.61

Source: Jinko Solar (2014a), own-table

Jinko Solar has a variety of module types, 4 types each for poly- and for mono-crystalline silicon. It is expected that customers should be able to have a varied choice between many kinds of modules. However, their efficiency is only on average compared to other products. The warranty is also similar to others, with a 10-year product warranty and a 25-year linear power warranty.

Table 60. Solar module specification of Jinko Solar

	Production name	Maximum power-Pmax (W)	Efficiency	Dimensions (mm)	Weight (kg)	Warranty
Poly-crystalline silicon[41]	JKM265P-60	245-265	14.97-16.19	1650*992*40	18.5	10-year product warranty, 25 year linear power warranty
	JKM310P-72	190-310	14.95-15.98	1956*992*40	26.5	
	JKM270PP-60	255-270	15.58-16.50	1650*992*40	18.5	
	JKM315PP-72	300-315	15.46-16.23	1956*992*40	26.5	
Mono-crystalline silicon	JKM210M-72	190-210	14.88-16.45	1580*808*35	14.5	
	JKM270M-60	250-270	15.27-16.50	1650*992*40	18.5	
	JKM270M-60	250-270	15.27-16.50	1650*992*40	18.5	
	JKM315M-72	295-315	15.20-16.23	1956*992*40	26.5	

Source: Jinko Solar (2014a), own-table

Jinko Solar also recorded a peak in total net revenues in 2011, earning 7,384 million RMB. Except for the year 2012, the company is operating profitably. Their total net revenues increased sevenfold between 2009 and 2013. In spite of market difficulties in 2013, the firm still achieved a net income. The sales volumes of silicon materials and silicon ingots takes in only a small portion, while silicon wafers are among their main products. The sales volumes of solar cells and solar modules have particularly increased explosively. The sales volume of solar modules was only 14.4 MW in 2009, however, rose up to 1,765.1 MW in 2013. The average selling price of solar products in Jinko Solar has decreased since 2009. The prices of silicon ingot, wafer, cell, and module were 4.0, 1.3, 1.6, and 3.8 RMB per watt, respectively in 2013.

Table 61. Financial statement of Jinko Solar

	2009	2010	2011	2012	2013
Total net revenues (Millions of CNY)	1,539.54	4,654.85	7,384.95	4,794.77	7,078.84
Operating profit (loss) (Millions of CNY)	122,47	989.92	315.89	(1,233.49)	645.55

[41] Based on sales in Asia pacific and Middle-East Asia.

Net income (loss) (Millions of CNY)		85,41	881.87	273.34	(1,542.42)	188.01
Sales volume	Recovered silicon materials (metric tons)	11.7	-	0.1	0.0	5.0
	Silicon ingots (MW)	0.01	2.1	2.7	1.1	0.3
	Silicon wafers (MW)	180.4	157.2	135.1	197.4	54.8
	Solar cells (MW)	27.3	55.1	51.8	78.5	113.2
	Solar modules (MW)	14.4	265.4	760.8	912.4	1,765.1
Average selling price (RMB)	Recovered silicon materials (per kilogram)	2,397.1	-	108.6	-	2.9
	Silicon ingots (per watt)	6.8	5.2	5.3	1.6	4.0
	Silicon wafers (per watt)	6.1	5.8	3.8	1.7	1.3
	Solar cells (per watt)	8.3	7.9	3.3	1.8	1.6
	Solar modules (per watt)	12.7	12.2	8.7	4.3	3.8

Source: Jinko Solar (2010; 2014b); Google finance (2014)

2.4.4.2. South Korean companies

OCI

OCI was established in 1959 with the name of Oriental Chemical Industries and its name was changed to the abbreviation OCI in 2009. OCI began to produce commercial polysilicon with a production capacity of 5,000 tons in 2008, and enlarged the capacity to 27,000 tons in 2010. As of 2013, OCI became the third-biggest polysilicon producing company in the world, with 5,200 employees and a production capacity of 42,000 tons. (DART, 2014). The company has been producing chemical products for more than 50 years, which are used for the green-energy industry such as solar energy, for the high-technology industry like semi-conductors and TFT-LCD, and in the automobile industry. The firm is divided into a basic chemical business part (solar energy related materials: polysilicon, soda ash, and special gas), a carbon-chemical business part (carbon black, pitch, and benzene) and one for other materials (sapphire ingot, solar energy generation, and cogeneration). It has 11 main integrated production facilities in South Korea, 2 production facilities in the U.S.A and one in China (DART, 2014). The firm has 104 domestic patents, 27 overseas patents, 30 domestic trade mark rights, and 5 overseas trade mark rights. Total sales, operating profit, net profit, debt ratio, and EBITDA (Earnings Before Interest, Tax, Depreciation and Amortization) of OCI are given in the table below. The total sales increased until 2011, but the company showed a negative development in recent years.

Table 62. Financial statements of OCI

	2009	2010	2011	2012	2013
Total sales (billion won)	2,728	3,311	4,276	3,218	2,955
Operating profit (billion won)	658	840	1,118	155	-106
Net profit (billion won)	428	650	865	13	-288
EBITDA (billion won)	907	1,172	1,571	699	422

Source: OCI (2013; 2014)

Hanwha group

Hanwha group established a vertical integration of solar energy production; polysilicon (Hanwha chemical), ingot and wafer (Hanwha solarone), cell (Hanwha Qcell, Hanwha solarone), and generating systems (Hanwha Qcell, Hanwha solarone) (Kang, 2014).

Hanwha Chemical was established in 1965 and has five business groups today: Polyethylene, Polyvinyl Chloride, Solar energy, Bio medical supplies, and Nano technology. Hanwha Chemical planned to produce 10,000 MT[42] of polysilicon in the first half year of 2014. It has 2,787 employees and five factories in South Korea, five corporations and four branches in overseas. Hanwha Chemical has been operated without deficits between 2009 and 2013. They recorded a number of 3,591.4 in total sales, 79.1 billion won of operating profit, and 115.9 billion won of net profit in 2013. The debt ratio in the years 2009 to 2013 lies between 80 and 93.1 percent.

Table 63. Financial statements of Hanwha group

	2009	2010	2011	2012	2013
Total sales (billion won)	3,033.7	3,628.2	3,970.4	3,559.0	3,591.4
Operating profit (billion won)	410.8	483.2	472.2	141.2	79.1
Net profit (billion won)	343.4	283.9	411.5	120.6	115.9
Debt ratio (%)	80.5	82.0	80.0	92.0	93.1

Source: Hanwha chemical (2013; 2014)

Hanwha SolarOne Co., Ltd (Shanghai) was established in 2006 and Hanwha solar Engineering Research and Development Center Co., Ltd., and Hanwha SolarOne Hong Kong Limited were established in 2007. Hanwha group took over the Chinese Solarfun Power Holding in 2010 which was renamed into Hanwha SolarOne Corporation. The company has been listed on the National Association of Securities Dealers Automated Quotations (NASDAQ) since 2011 with the symbol of HSOL (Hanwha SolarOne, 2014). As of 2013, 7,005 employees work for the company, and it has 52 patents in China. The annual production capacity of PV modules, PV cells, ingots and wafers are 1.5 GW, 1.3 GW and 800 MW, respectively. Hanwha SolarOne produces poly-crystalline with a conversion efficiency rate of 16.5 percent, and mono-crystalline solar cells that show 18 percent efficiency.

Table 64. Solar cell Specification of Hanwha SolarOne

	Size (mm)	Conversion efficiency (%)	Thickness (microns)	Maximum power output (W)
Poly-crystalline silicon	156 *156 ± 0.5	Up to 16.5	220 ± 20	4.28 W
Mono-crystalline silicon	125*125 ± 0.5	Up to 18	200 ± 20	

Source: Hanwha SolarOne (2014)

Hanwha SolarOne gives a 12-year product warranty which is the longest warranty among competitors. The company has various sorts of solar modules. The product SF160 Mono x-tra presents the highest efficiency of 18.0 percent among all analyzed products.

[42] MT: meric ton

Table 65. Specification of solar modules of Hanwha SolarOne

	Production name	Maximum power-Pmax (W)	Efficiency	Dimensions (mm)	Weight (kg)	Warranty
Poly-crystalline silicon[43]	HSL 60 Poly	240-265	14.8-16.4	1636*988*40	19±0.5	12 year product warranty, 25 year linear performance warranty
	HSL 72 Poly	290-315	15.0-16.3	1956*988*45	27 ± 0.5	
	SF190 Poly x-tra	195-220	15.0-16.9	1494*1000*35	16	
	SF220 Poly x-tra	230-255	15.8-17.5	1652*1000*45	20 ± 0.5	
	SF260 Poly x-tra	275-300	15.8-17.1	1966*1000*50	26	
Mono-crystalline silicon	SF160 Mono	170-195	15.4-17.6	1580*808*40	14	
	SF160 Mono x-tra	170-200	15.4-18.0	1580*808*35	14	
	HSL48 Mono	190-214	14.2-16.1	1338*1000*35	15.5±0.5	
	HSL60 Mono	240-265	14.5-16.0	1652*1000*45	20±0.5	

Source: Hanhwa SolarOne (2014)

The total net revenues of Hanwha SolarOne have fluctuated since 2009, reaching a revenue of 4,725.69 million RMB in 2013. However, since 2011 an operating loss and a net loss have been recorded. In 2011 and 2012, the company had a negative gross margin, which turned positive in 2013.

The volume of produced ingot and wafer has fluctuated since 2009. In 2013, the quantities of produced ingot and wafer were 224.1 and 227.6 MW. The volume of produced PV cells and shipped PV modules has been steadily increasing to a fourfold amount in 2013, compared to 2009. For example, 896.5 MW of produced PV cells and 1,280.3 MW of shipped PV modules were recorded in 2013. The average selling price of PV modules is sharply decreasing. Hanwha SolarOne had an average selling price of PV modules of 4.1 RMB per watt in 2013.

Table 66. Financial data and general information of Hanwha SolarOne

	2009	2010	2011	2012	2013
Total net revenues (thousand RMB)	3,778,316	7,548,545	6,416,485	3,678,380	4,725,692
Operating profit (loss) (thousand RMB)	117,912	1,184,501	(1,096,436)	(1,180,600)	(406,748)
Net income (loss) (thousand RMB)	(145,227)	757,357	(930,104)	(1,562,859)	(874,090)
Gross margin (%)	11.5	22.2	(3.4)	(8.8)	7.1
General information					
Volume of ingots produced (MW)	154.1	360.0	367.2	237.7	224.1
Volume of wafer produced (MW)	164.6	387.4	383.7	242.6	227.6
Volume of PV cells produced (including PV cell processing) (MW)	260.2	502.4	687.3	708.4	896.5
Amount of PV modules shipped (MW)[44]	313.4	797.9	844.4	829.8	1,280.3
Average selling price of PV modules (RMB/W)[45]	15.27	11.58	8.87	4.47	4.10

Source: Hanhwa SolarOne (2014)

[43] Based on sales in Asia pacific and Middle-East Asia.
[44] Including PV module processing
[45] Excluding PV module processing

In 2012, Hanwha group took over the German company Qcells that turned into Hanwha Qcells. The previous Q-Cells AG was established in 1999 and launched its solar cell production in 2001. Today, Hanwha Qcell has 200MW solar cell capacity in Germany, and 900MW capacity in Malaysia. The poly-crystalline solar cell efficiency of Hanwha Qcells is in between 16.6 and 18.0 percent and the mono-crystalline cell efficiency shows between 18.2 and 19.8 percent.

Table 67. Solar cell specification of Hanwha Qcells

	Product name	Nominal power (W)	Efficiency (%)	Thickness (microns)	Format (mm)
Poly-crystalline	Q6LPT3-G3	4.04-4.38	16.6-18.0	180/200 ± 30	156*156 ± 0.5
Mono-crystalline	Q6LMXP3-G3	4.43-4.82	18.2-19.8	200 ± 30	156*156 ± 0.5

Source: Hanwha Qcells (2014)

The poly-crystalline solar module efficiency of Hanwha Qcells confirmed as between 14.7 and 16.3 percent and the mono-crystalline solar module efficiency lies between 15.9 and 16.8 percent. The product warranty is 12 years and linear performance warranty is 25 years, similar to the Chinese sister Hanwha SolarOne.

Table 68. Solar module specification of Hanwha Qcells

	Production name	Maximum power-Pmax (W)	Efficiency (%)	Dimensions (mm)	Weight (kg)	Performance warranty
Poly-crystalline	Q.PRO-G3 250-270	250-270	15.0-16.2	1670*1000*35	19	12-year product warranty and 25-year linear performance warranty
	Q.PRO BLK-G3 245-265	245-265	14.7-15.9	1670*1000*35	19	
	Q.PRO L 295-315	295-315	15.3-16.3	1956*988*45	27 ± 0.5	
Mono-crystalline	Q.PEAK-G3 265-280	265-280	15.9-16.8	1670*1000*35	19.0	
	Q.PEAK S-G3 215-225	215-225	15.9-16.7	1348*1000*35	15.5	

Source: Hanwha Qcells (2014)

Except for the year 2009, the sales revenues of Solar Qcells increased between 2006 and 2010. Sales revenues, operating income, and net income of Solar Qcells were 1,354.2, 82.3, and 18.9 million Euros in 2010. The capacity of solar cells was 1,100 MWp and the capacity of thin-film modules was 135 MWp in 2010.

Table 69. Financial statement and production of Solar Qcells (2006-2010)

	2006	2007	2008	2009	2010
Sales revenues (million Euro)	539.5	858.9	1,195.1	790.4	1,354.2
Operating income (million Euro)	129.4	197.0	191.8	-362.5	82.3
Net income (million Euro)	97.1	148.4	177.3	-1,342.9	18.9
EBITDA (million Euro)	147.2	222.0	237.5	-209.0	182.2
Capacity solar cells (MWp)	336	516	760	800	1,100
Production solar cells (MWp)	253	389	570	537	939
Capacity thin-film modules (MWp)	-	-	10	30	135
Production thin-film modules (MWp)	-	-	4	14	75

Source: Solar Qcells (2010)

2.4.4.3. Japanese companies

Sharp

In 1912, Tokuji Hayakawa established a small metalworking shop in Tokyo and invented a mechanical pencil with the name 'Ever-Ready Sharp Pencil' in 1916. The company name, Sharp Corporation was later derived from this invention. More than 100 years later, in March 2014, Sharp employs 24,118 people in Japan, and 26,135 employees are working for the company overseas. Sharp already began to develop solar cells in 1959 and released the first solar-cell battery calculator in 1976. In 1992, the company achieved a cell conversion efficiency of 17.1 percent for polycrystalline solar cells, and even 22 percent for single-crystal type solar cells. The company realized 35.8 percent conversion efficiency in its triple-junction compound solar cell in 2009. The warranty for the solar modules is 10-year product guarantee and 25-year linear performance guarantee. The solar cell business had a share of 9.6 percent within the Sharp group in 2013.

Table 70. Solar module specification of Sharp

	Production name	Maximum power-Pmax (W)	Efficiency	Dimensions (mm)	Weight (kg)	Warranty
Poly-crystalline silicon[46]	ND-R245A5	245	14.9	1652*994*46	19.0	10-year product guarantee, 25-year linear performance guarantee
	ND-R245A6	245	14.9	1652*994*46	19	
	ND-R250A5	250	15.2	1652*994*46	19	

Source: Sharp UK (2014)

Unlike other companies, Sharp Corporation introduced thin-film solar products. The maximum power of the product lies between 120 watt and 135 watt, with an efficiency between 8.6 percent and 9.6 percent.

Table 71. Thin-film specification of Sharp

	Production name	Maximum power-Pmax (W)	Efficiency (%)	Dimensions (mm)	Weight (kg)
Thin-film (amorphous, microcrystalline)	NA-E120L5	120	8.6	1402*1001*6.7	24
	NA-E125L5	125	8.9	1402*1001*6.7	24
	NA-E130G5	130	9.3	1402*1001*7.4	26
	NA-E130L5	130	9.3	1402*1001*6.7	24
	NA-E135G5	135	9.6	1402*1001*7.4	26
	NA-E135L5	135	9.6	1402*1001*6.7	24

Source: Sharp UK (2014)

Looking at the financial statement of Sharp, the firm recorded total net revenues of 2,478.59 billion yen in 2013, which slightly varied since 2009. The company operated in black in 2010 and 2011 whereas operating losses and net losses occurred in the following two years. The operating losses were 21,982 million yen in 2012 and 4,497 million yen in 2013.

[46] Based on sales in Asia pacific and Middle-East Asia.

Table 72. Financial statement of Sharp

	2009	2010	2011	2012	2013
Total net revenues (Millions of Yen)	2,847,227	2,755,948	3,021,973	2,455,850	2,478,586
Operating profit (loss) (Millions of Yen)	(55,841)	51,903	78,896	(337,552)	(146,266)
Net income (loss) (Millions of Yen)	(125,815)	4,397	19,401	(376,076)	(545,347)
Solar cells sales in the group (Millions of Yen)	157,095	208,732	265,492	223,869	259,895

Source: Sharp (2014)

Kyocera

Kyoto Ceramic Co., Ltd was established in Kyoto with 28 employees in 1959. Kyocera was listed on the First Section of the Tokyo and Osaka Stock Exchanges in 1974 and on NYSE in 1980. Kyocera Solar, Inc. was founded in Arizona, U.S.A in 1999 and Kyocera Solar Energy Co., Ltd (Tianjin) was established in 2003. As of March 2014, 69,789 employees around the world are working in 230 group members. The group's consolidated sales consist of 21 % information equipment, 19.6 % electronic devices, 18.9 % applied ceramic products, 13 % semiconductor components, 12.9 % telecommunication equipment, 5.5 % fine ceramic components, and 8.8 % other products.

The specifications of the products are similar to other companies, except for the KD70SX-1P. It is a poly-crystalline smaller and lighter than all other products in the range.

Table 73. Solar module specification of Kyocera

	Production name	Maximum power-Pmax (W)	Efficiency (%)	Dimensions (mm)	Weight (kg)	Performance warranty
Poly-crystalline	KD145GH-4FU	145	14.4	1500*668*46	12.5	10 years on 90% and 25 years on 80 % of the minimally specified power P under standard test conditions
	KD195GH-4FU	195	14.7	1338*990*46	16	
	KD220GH04FU	220	14.8	1500*990*46	18	
	KD245GH-4FB2	245	14.8	1662*990*46	20	
	KD250GH-4FB2	250	15.1	1662*990*46	20	
	KD255GH-4FB2	255	15.4	1662*990*46	20	
	KD140SX-1YU	140	13.9	1500*668*46	12.5	
	KD145SX-1YU	145	14.4	1500*668*46	12.5	
	KD70SX-1P	70	13.6	778*660*36	8.5	

Source: Kyocera solar Europe (2014)

The company Kyocera has been operated without losses since 2009. The total net revenues, operating profit, and net income in 2013 were 1,280.05, 76,926, and 67,351 billion yen, respectively.

Table 74. Financial statement of Kyocera

	2009	2010	2011	2012	2013
Total net revenues (Millions of Yen)	1,128,586	1,073,805	1,266,924	1,190,870	1,280,054
Operating profit (loss) (Millions of Yen)	43,419	63,860	155,924	97,675	76,926
Net income (loss) (Millions of Yen)	14,023	7,415	130,118	84,758	67,351

Kyocera (2010); (2014)

2.4.5. Policy Analysis

Solangi et al (2011: 2150) define energy policy as follows;

> *Energy policy is a strategy in which government decides to address the issues of energy development along with the development of the energy industry to sustain its growth; including energy production, distribution and consumption. The attributes of energy policy may include legislation, international treaties and incentives to investment. It plays a vital role to mitigate the impacts of global warming and crisis of energy availability.*

As Solangi et al. described, energy policy is important not only for domestic energy controlling but also international energy security. Without policies supporting the renewable energy technology, it would be very difficult to deploy the technology itself due to economic reasons. Therefore, analyzing renewable energy related policies is crucial for market analysis of renewable energy in the countries.

The renewable energy policies in China, South Korea, and Japan, were established and have been amended. The Renewable Portfolio Standard (RPS) and the Feed-in Tariff (FIT) are representative policies in the field. The RPS defines that retail electricity suppliers should supply a certain amount of electricity from renewable energies. A weak RPS can be voluntary without compliance while a strong RPS is obligatory with fines (Lo, 2013). FIT is a policy that supports renewable electricity generators' price in the market. Even though there are many debates among scholars and politicians internationally, no theoretical barriers were found. The following table 75 describes the renewable energy policy situation in three countries.

Table 75. Renewable energy supporting policy situation in East Asia

	FIT	RPS	Net metering	Bio fuel duty system	Heat duty system	RE deal certificate
China	O	O		O	O	
S.Korea		O	O	O		O
Japan	O	O	O			O
	Financial subsidy, Rebate	Tax deduction for investment and production	Tax reduction for sales, energy, and VAT etc	Energy production refund	Public investment loan	Public competition bidding system
China	O			O	O	O
S.Korea	O	O	O		O	O
Japan	O				O	

Source: KIMR – Korea Industrial Marketing Research (2013)

In this part, the solar energy policy in China, South Korea, and Japan will be analyzed with institutional viability indicators by IRENA. The institutional feasibility helps to understand a policy's potential to succeed or fail (IRENA, 2014). Following are the political viability indicators.

Table 76. Political viability indicators

Issued addressed	Indicators
Existence of stakeholder support	• Existence of related policy, programs, plans, strategies, laws and activities • Register of stakeholders involved and their official viewpoint • Policy origins: developed internally in response to local ambition, or response to pressures from external bodies
Stability of stakeholder support	• Consistency of government targets • Longevity of financial political commitments • Existence of incentives for stakeholders to comply with policy
Influence of stakeholder groups	• Ownership concentration of key industries • Power and organization of the public
Credibility of the policy	• Results achieved/ anticipated according to the evaluation of other criteria
Political appropriateness and acceptability of new development	• Political system • Importance of (renewable) energy to public • Stage of the electoral cycle • Rationale for deploying renewable technologies-compatibility or conflicts with other policy priorities

Source: IRENA (2014: 37)

After the renewable energy policies focusing on RPS and FIT are briefly described for each country, the indicators will be further analyzed.

2.4.5.1. Policy analysis in China

Renewable energy policies have been discussed in China since mid-1990s. The renewable energy promotion plan was made in 2003 and the renewable energy law was promulgated in 2005. Table 77 summarizes the development of renewable energy policies in China.

Table 77. China's renewable energy policies

Year	Policy name
1996	9th Five-Year-Plan (1996-2000) 2010 New and Renewable Energy Development Program by the State Economic and Trade Commission (SETC), the State Planning Commission (SPC), and the State Science and Technology Commission (SSTC)
2001	10th Five-Year-Plan (2001-2005) Renewable Energy Commercialization Development by the State Economic and Trade Commission (SETC)
2003	Renewable Energy Promotion Plan
2005	Renewable Energy Law
2007	Medium and Long-term Renewable Energy Development Plan

Source: Shyu (2010: 42)

The National Development and Reform Commission (NDRC) which is responsible for planning the economic development of the nation as well as for energy and climate change, introduced the RPS in China in 2007 (Lo, 2013). Looking at the RPS program, the target for grid companies is to achieve one percent non-hydro renewable power by 2013 and three percent by 2020. For generators, the goal is three percent non-hydro renewable power by 2010, and eight percent by 2020. Lo argued that RPS in China is weak or only voluntary due to the lack of monitoring and compliance requirements. The six largest generators in China could not meet the 3 percent renewable energy goal in 2010 (Lo, 2013).

Therefore, in 2011, the NDRC started improved plans to solve the problem. First of all, relying on their conditions and capacities, each target was allocated to generators and grid firms. Second, the targets of grid companies were increased to induce incentives to purchase renewable electricity. One of the largest grid companies in China, State Grid's goal is 4.8 percent non-hydro renewable energy by 2015. Third, the monthly monitoring system of compliance was developed by the National Energy Administration (NEA). Fourthly, if the goal was not to be achieved, the negative impact influences on the mangers' performance evaluation (Lo, 2013).

In spite of the efforts, China's RPS system still has problems. Firstly, the RPS in China does not distinguish among different renewable energies. For instance, as a low cost renewable energy, wind power would dominate in the renewable energy market over solar PV which produces relatively high cost renewable energy. Second, the punishments for non-compliance are vague. There are no financial fines for non-compliance, which has been proved as effective action in international experience (Lo, 2013).

The Feed in Tariff (FIT) was introduced in 2003 in order to develop wind power in China. The system began to support wind power at first and was determined on a case-by-case basis. However, this has resulted in inefficient power generators. The NDRC decided to change baseline price from 0.51 Reminbi (RMB)/ kWh to 0.61 RMB/kWh relying on the wind farm area in 2009. The NDRC set solar FIT price at 1.00 RMB/kWh in 2011. Lo (2013) mentions that China's FIT for solar PV is not enough to offer incentives for generators and is lower than in other countries. He also points out that the FIT should be considered by regional character because China is huge country and the solar output and cost to produce electricity are vary due to geographical differences. (Lo, 2013: 510)

Table 78. Comparing China's solar power FITs internationally.

Country	Solar power FIT (RMB/kWh)
China	1.00
Canada (Ontario)	2.80-2.96
Germany	1.71
Spain	2.34
United Kingdom	0.69-1.55
Ukraine	1.97
Malaysia	2.57-3.59

Source: Lo (2013: 510)

China also provides direct subsidies for renewable energy supply. The Ministry of Finance in China implemented two solar PV power subsidy programs for domestic demand. First, the Solar Roofs program which supports solar PV rooftop system deployment and building integrated photovoltaic systems. The subsidies are 7.5 RMB/W for rooftop systems and 9RMB/W for building integrated photovoltaic systems in 2012. Second is the Golden Sun Demonstration project, supporting not only rural electrification projects but also large-scale photovoltaic power projects. This subsidy supports 50 percent of the total cost for on-grid systems and 70 percent for off-grid systems in rural regions. The subsidies are 5.5 RMB/W for on-grid systems and 7.0/W for off-grid systems (Zhang and He, 2013).

In the following part, the viability indicators of renewable energy policy in China will be analyzed.

Existence of related policy, programs, plans, strategies, laws and activities

'The renewable energy law' of the People's Republic of China was adopted at the 14th meeting of the standing committee of the tenth national People's congress in 2005 and was amended in 2009 (MOFCOM, 2013). In chapter two, it includes a resource survey and a development plan, and in chapter three, industry guidance and technology support. Chapter four provides information on promotion and application, and chapter five, price management and fee sharing. Chapter six consists of economic incentives and supervisory measures and chapter seven legal responsibilities. In article 7, the government sets plans for middle and long-term renewable energy development.

> *Energy authorities of the State Council sets middle and long-term target of the total volume for the development and utilization of renewable energy at the national level, which shall be implemented and released to the pubic after being approved by the State Council (NPC, 2005).*

The energy authorities of the State Council are supposed to cooperate with provinces, autonomous regions and municipalities to meet the goal of total volume. In fact, the 'Renewable energy scale-up program' was planned together with the Chinese government and the World Bank in 2005. A total of 228.82 million USD was invested for the Chinese local government (the World Bank, 2012).

There are several programs for solar energy such as the Brightness Program (1996), the Township Electrification Program (2002), the Rooftop Subsidy Program (2009), Golden Sun Demonstration program (2009), and the PV Concession program (2009) (Zhang and He, 2013).

In the 12th Five-Year plan for National Economic and Social Development, China set up plans to generate 11.4 percent of non-fossil resources in primary energy consumption by 2015 and 15 percent by 2020. Cumulative 15 GW production of solar energy is supposed to be achieved by 2015 (IEA, 2012b).

Especially in JiaXing City, they have strategies to develop the solar energy industry. Strategies are hot water engineering and technology innovation as well as building integrating solar energy technology innovation (Yang et al. 2012).

In 2007, the NDRC introduced a 'Medium and Long-term Development Plan for Renewable Energy'. According to the law, China would achieve 300 MW by 2010 and 1.8 GW of solar power by 2020. 300 MW accumulated capacity of solar PV for rural areas will be installed by 2020. 1 GW of building-integrated grid-connected PV (BIPV) will be installed by 2020. China aims to generate 200 MW for grid-connected solar PV power stations and 200 MW for solar thermal power stations by 2020 (NDRC, 2007).

China's renewable energy deployment targets can be summarized as below in table 79. The target of solar PV deployment by 2020 is 50 GW.

Table 79. Renewable energy deployment targets in China (Capacities by year)

Renewable Energy Source	2005	2010	2020
Hydropower	117 GW	200 GW[a]	380 GW[b]
Biomass Power	2 GW	5.5 GW	30 GW[b]
Wind Energy	1.26 GW	42 GW[a]	200 GW[b]
Solar PV	0.07 GW	0.6 GW[a]	50 GW[b]
Bioethanol[c]	1.02 million tons	2 million tons	10 million tons
Biodiesel[d]	50,000 tons	200,000 tons	2 million tons
a. Actual installed capacity for 2010. b. Reported new target. c. Non-food grains used as feedstock. d. From waste and edible oil sources.			

Source: Campbell (2014: 8)

Register of stakeholders involved and their official viewpoint

The Chinese Renewable Energy Industries Association (CREIA) was founded in 2000. The association consists of more than 200 members from the business area, academics, organizations and individual professionals. They introduce themselves on its web-site as a *bridge between regulatory authorities, research institutes, and industry professionals, in order to provide a forum to discuss renewable energy development at the national level and subsequently advise the Government of China on strategic policy formulation (CREIA, 2012).* They also provide a forum to raise their concerning voice.

Policy origins

According to IRENA (2014) policy origins are either developed internally in response to local ambition (endogenous), or a response to pressures from external bodies (exogenous).

The author argues that the policy origin of renewable energy policies in China is endogenous. The reasons are as follows: First, the renewable energy law was formed due to the necessity of the nation expressed in the law: energy security, protecting environment, and sustainability of economy and society. Article 1 of 'Renewable energy law' states as follows:

> *In order to promote the development and utilization of renewable energy, improve the energy structure, diversify energy supplies, safeguard energy security, protect the environment, and realize the sustainable development of the economy and society, this Law is hereby prepared (NPC, 2005).*

The State Council even stressed renewable energy including solar PV industry as a new strategic industry. The government promotes a revolution of energy production and consumption, and advancing ecological structure (Zhang and He, 2013). The administration recognizes the importance of self-dependent innovation abilities for renewable energy research and development and industry development system (Zhang et al. 2013). Zhang et al (2013), further mention that the Chinese government obviously recognized the significance of green development, taking the leadership of the green industries, and innovation of domestic capacity.

Consistency of government targets

Below table 80 shows that the target of solar energy development by the government has been achieved. For example, the government set a goal installing 80 MW of solar power by 2006 and China achieved 85 MW in 2006. Another goal of solar power capacity by 2010 was 300 MW and they finally achieved even 550 MW in 2010. The goal of solar water heater by 2010 was 105 GWth[47] and they nearly achieved recording 102 Gwth in 2010. Therefore, we can conclude that the government targets of solar energy are consistent.

Table 80. Solar energy goals and actual achievement in China

	2006	Actual in 2006	Target of total capacity by 2010	Actual in 2010	By 2020
Solar Power	80 MW	85 MW	300 MW	550 MW	1.8 GW
Solar PV in remote rural areas	-	-	150 MW	-	300 MW
BIPV	-	-	50 MW	-	1 GW
Large-scale, grid-connected solar PV power station	-	-	20 MW	0	200 MW
Solar thermal power station	-	-	50 MW	-	200 MW
Solar water heater	100 MW	-	150 Million m^2 , 105 GW_{th}	102 GW_{th}	300 Million m^2 , 210 GW_{th}

Source: own compilation based on NDRC (2007); REN21 (2011); Shyu (2010)

Longevity of financial political commitments

The Ministry of Finance, Ministry of Science and Technology and the National Energy Administration of the National Development and Reform Commission introduced the Golden Sun program in 2009. The 50 percent of investment for solar power project will be subsidized by the government (Lin, 2014). However, the tariff was decreased by 5.5 Yuan from 7 Yuan announced by Ministry of Finance in 2012 (Patton, 2012). Therefore, we can conclude that the longevity of financial support exists in China; however, the amount of financial commitment has been reduced.

[47] Th: thermal unit

Existence of incentives for stakeholders to comply with policy

There are incentives for stakeholders of solar energy in China. The amended Renewable Energy Law in 2009 states that electricity grid companies should buy all electricity generation from renewable energy producers. If power companies refuse to fulfill the rule, they are fined the amount up until twice the 'economic losses' from the renewable energy generators (Campbell, 2014).

The financial incentives for renewable energy projects are received from national and provincial governments. The Golden Sun program offers an investment subsidy of 50 percent for solar power projects. The support for solar PV projects for the developer's own use is 5.5 Yuan per watt (Campbell, 2014).

The ministry of Finance and the Ministry of Housing and Urban-Rural Development of China provide RMB 20/W for BIPV systems (Zhang and He, 2013).

Ownership concentration of key industries

Most of the important industries in China such as energy, aerospace, telecom, banking, steel and others, are managed by the government. State-owned Assets Supervision and Administration Commission of the State Council (SASAC) enumerate 117 state owned enterprises in China on the web-site (SASAC, 2008). The five big generation companies also belong to government. Energy prices and project decision, and management of renewable energy development are controlled by the NDRC. After latest reforms, the National Energy Commission (NEC) conducts energy policy strategies in China. The central government mostly drafts laws to promote renewable energy and makes laws with provincial and local government (Campbell, 2014). Therefore, it is difficult for the stakeholder groups to influence related laws.

Power and organization of the public

In China, the political power of the public is weak. The central government still retains superior status over the citizens due to a legacy of the institutional environment. The public is only restrictively allowed to participate in policies. Chen Hubbard (2012) conducted a case study *on power relations and risk allocation in the governance of public private partnerships.* He found out that on one hand, the public private partnership projects were able to be successful thanks to government's supports. On the other hand, the contracts were less effective due to state dominance and the weak legal system.

Yu (2013) insists that there are drawbacks of the legislation system because it is hard for the public to participate. The legislators lead the process of opinion presentation and the citizens only participate under the legislators' controls (ibid: 63)

Results achieved/ anticipated according to the evaluation of other criteria

The China Renewable Energy Scale-up Program (CRESP) is a program where the banks, Global Environment Facility (GEF), and the Chinese government participate in order to promote renewable energy generation. NRDC, the World Bank, and GEF were preparing to establish the CRESP program in 1999 and in 2004. 87.0 million USD and 86.3 million USD were loaned to China under the project names of 'CRESP' and 'Follow-up to CRESP Phase I' (the World Bank, 2012). The Key performance indicators read as follows:

- *Increased renewable electricity (GW) and production (TWh/year)*
- *Reduced emission of carbon, NO_x, SO_x and particulates*
- *Market framework established*
- *Environment for development of renewable improved*
- *Improved quality and reduced cost among manufacturers and service providers in wind and biomass (the World Bank, 2012: 2-3)*

The Implementation Completion and Result Report, rated the Chinese governments' performance as 'Highly satisfactory', the implementing agencies as 'satisfactory', and also the overall borrower performance as 'satisfactory'. The Potential Problem Project was at any time was rated as 'no', and the Problem Project at any time was evaluated as 'no' as well (the World Bank, 2012).

The CRESP led the Chinese government to enact the renewable energy law, and the local government in China developed incentives for renewable energy. The renewable electricity increased from 35 TWh/ year in 2000 to 146 TWh/ year in 2010 (the World Bank, 2012). Overall, it is estimated that the Chinese government well performed the CRESP program.

Political system

China is a socialist country ruled by the Communist Party of China (CPC). Lo (2013) argues that China currently has become more decentralized since reforms came into action. Decentralization brings economic development causing to share powers, resources, and responsibilities with the local government.

The government in China, carries out the targets with the policy mechanism 'Target responsibility system' and 'Pilot programs'. The administration governs the target responsibility system with target allocation system, monitoring system, and evaluation system. The provinces can be punished when they do not carry out the goal (Lo, 2013). On the other hand, provinces and cities are able to participate in the pilot programs voluntarily. Under the management of the NDRC, the Low-Carbon Province and City pilot program in 2010, policies started: *the specific obligations and commitments include developing a long-term low-carbon development plan; and exploring institutional reform and effective policy instruments to lower* *carbon emissions etcetera (Lo, 2014: 3).* With these two strong and soft policy schemes, the political system for political appropriateness and acceptability of new development is strong.

Importance of (renewable) energy to public

There are many words to describe China; the world most populous country (1.3 billion population in 2013), the fastest economic growing country (growing annually 9.8 percent during last three decades), and the most electricity consuming country (5,322.3 TWh/year in 2013), etcetera (Campbell, 2014). In order to supply the electricity to fulfil these facts, China is confronted with energy secure problems.

China is the largest coal consumer and producer in the world (EIA, 2013c). Like we examined above, coal accounts for 70 percent of total energy consumption in China. Needless to say, burning coal brings sulfur dioxide, oxides of nitrogen, and particulate emissions which raise greenhouse gas emissions. This fact threatens not only the Chinese population but also the global environment. Therefore, China has been trying to develop renewable energy instead of using more fossil fuels (Campbell, 2014).

Stage of electoral cycle

This indicator is about how much time there is for carrying out a policy within a given electoral cycle in the government.

The constitution of the People’s Republic of China, Article 60 and 98 mention that *the National People’s Congress is elected for a term of five years. Deputies to the people's congresses of counties, cities not divided into districts, municipal districts, townships, ethnic townships and towns are elected directly by their constituencies. The term of office of local people's congresses at various levels is five years (Chinese constitution, 2004).*

The new government took office at the end of 2012 and the presidency term of the president in China is five years, he or she is limited to two consecutive terms (Chinese constitution, 2004). Traditionally, the president serves two consecutive terms or 10 years in China. According to the relative early stage of the electoral cycle in China, it can be estimated that the current renewable energy policies would be continued. In addition, given the single party system in China, that is the communist party, it can be anticipated they would also in future carry out policies for renewable energy.

Rationale for deploying renewable technologies

The reasons for deploying renewable technologies in China are not only to protect the environment but also to accomplish green economic development. The basis can be confirmed by the Green Development project. During China’s 12th Five-Year Plan, Green Development is being emphasized to achieve green economy. The six strategic points are mentioned: *Respond to climate change, strengthen resource saving and management, develop the 'circular economy', enhance environmental protection, promote ecosystem protection and recovery, and strengthen systems for water conservation and natural disaster prevention* (IEA, 2011b: 16). The energy-efficiency technology demonstration and diffusion programs are also highlighted in order to save energy and to have new growth opportunities (IEA, 2011b).

The contradictory goals 'protecting environment and developing economy' are crucial for China. The renewable energy can be a solution to catch two birds with one stone.

Below table is the evaluation of solar energy political viability in China.

Table 81. Evaluation of solar energy political viability in China

Indicators	Evaluation
• Existence of related policy, programs, plans, strategies, laws and activities	O
• Register of stakeholders involved and their official viewpoint	O
• Policy origins: developed internally in response to local ambition, or response to pressures from external bodies	endogenous
• Consistency of government targets	O
• Longevity of financial political commitments	∆
• Existence of incentives for stakeholders to comply with policy	O
• Ownership concentration of key industries	Many by government
• Power and organization of the public	Weak
• Results achieved/ anticipated according to the evaluation of other criteria	Satisfactory
• Political system	Communism but more decentralized than before reformation
• Importance of (renewable) energy to public	Growing economy, the most electricity consuming country
• Stage of the electoral cycle	Comparatively early
• Rationale for deploying renewable technologies-compatibility or conflicts with other policy priorities	Green economy development

2.4.5.2. Policy analysis in South Korea

In South Korea, the new and renewable energy laws and plans have been developed since 1987. The 'Act on the promotion of the development, use and diffusion of new and renewable energy' was completely revised in 2004. The new and renewable energy supplying target is eleven percent by 2035.

Table 82. Development process of new and renewable energy policies in South Korea

Year	Related law, basic plan	Main contents
1987	Enactment of 'Act on promotion of replacement energy development'	Preparing legal basis of replacement energy R&D activities and supports
1997	Revision to Act on promotion of development, use, diffusion of replacement energy	Supplying 2 % of replacement energy by 2006.

2002-03	Amend Act on promotion of replacement energy development’	Introduction of FIT. Set-up 5 % of new and renewable energy supplying target by 2011
2004	Complete revision to ‘Act on the promotion of the development, use and diffusion of new and renewable energy’	Complete definition revision to new and renewable energy.
2008	The third basic plan of new and renewable energy technology development, use, diffuse	Revision of target of 11% of new and renewable energy supplying by 2030
2012	Substitution FIT to RPS	Abolition FIT
2014	The fourth new and renewable energy basic plan	Revision of target of 11% of new and renewable energy supplying by 2035

Source: Lee SH (2014: 66)

The definition of FIT –Feed in Tariff (발전차액지원제도) in South Korea, is the system which supports the gap between the price of electricity generated by new and renewable energy and standard price designated by the minister of the Ministry of Knowledge Economy. The policy has been enforced since 2002 in South Korea (So, 2012). However, the policy supporting renewable energy in South Korea was changed from Feed-in Tariffs (FIT) to Renewable Portfolio Standards (RPS) in 2012. The RPS system is that the electricity suppliers should produce certain amounts of electricity from renewable energy resources. The government imposes the duty on 13 generating companies which have more than 500MW generating facilities. Following, are the application sources: Solar PV, wind power, hydro, tidal, biogas, landfill gas, biomass, fuel-cell, integrated gasification combined cycle (IGCC), waste, and refuse derived fuel. The obligated enterprises have to generate at least 10 percent with renewable energies by 2022 (Lee SH, 2014).

Existence of related policy, programs, plans, strategies, laws and activities

In South Korea, the ‘Act on the promotion of the development, use and diffusion of new and renewable energy’ was introduced in 2004 and amended 24 times as of June 2014. It consists of 35 articles and includes definitions in article 2, annual implementation plans, and project funding for technological development etcetera. The purpose of its establishing is stated in its article 1: *the purpose of this Act is to contribute to the preservation of the environment, the sound and sustainable development of the national economy, and the promotion of national welfare by diversifying energy sources through the promotion of technological development, use and distribution of new energy and renewable energy, and the activation of the new energy industry and the renewable energy industry, and by promoting the stable supply of energy, environment-friendly conversion of the energy structure, and the reduction of greenhouse gas emissions (MOTIE – Ministry of Trade, Industry and energy, 2014a).*

The promotion of photovoltaic facilities for residential houses (One million green homes project), is a government supported policy to fund the installment of renewable energy generation facilities in private residences of one million buildings by 2020. The support scale is less than 3kW per house for solar PV and less than 20m^2 for solar thermal (KNREC, 2014).

There are more projects for commercial buildings, local governments, renewable energy financial support, and certification programs.

In South Korea, the goals for the solar energy industry by 2030 are as follows: 25 percent of global market share, 250,000 domestic job creation, and 90 trillion won export.

Table 83. Solar energy industry goal in South Korea

	2015 (short-term)	2020 (mid-term)	2030 (long-term)
Global market share (%)	15	17	25
Domestic job creation	30,000	100,000	250,000
Export (trillion won)	17	30	90

Source: KOPIA (2014)

In 2014, 103.4 billion Korean won are prepared for financial support programs. The target of support are those who want to install for example solar module production lines or wind power turbine production lines. The support rates are 90 percent for small sized business, 70 percent for middle sized companies, and 30 percent for big enterprises.

Following are the strategies by Ministry of Knowledge Economy: strategic R&D industrialization, Market creation by promoting industrialization, Promotion for export, Establishing foundation of growth for firms (MKE, 2010).

Register of stakeholders involved and their official viewpoint

In Korea, there are associations related with renewable energy such as the 'Korea new and renewable energy association (KNREA)' and the 'Korea photovoltaic industry association (KOPIA)'. In fact, these two organizations gather opinions from group members and submit proposals to the government such as 'new and renewable energy electricity generation standard price revision'.

KNREA, founded in 2005 has been established '*to protect and enhance the rights and interests of our members and contribute to boosting the renewable energy industry and ultimately the national economy through promoting technology development and exports of renewable energy in Korea' (KNREA, 2014).* They work to enhance regulations concerning the renewable energy business development, help firms to enter overseas markets, and hold seminars on renewable energies.

KOPIA is a non-profit organization and national PV association supporting photovoltaic industry was established in 2009. Their objectives *'are to establish the best legal framework to boost the Korean PV industry, facilitate PV business opportunities through market research and support, stimulate interest in cutting-edge PV technologies & application, and raise the public awareness of PV by providing the best information and knowledge possible (KOPIA, 2014).*

Policy origins (endogenous or exogenous)

The Act on the promotion of the development, use and diffusion of new and renewable energy occurs endogenous in South Korea. The act was made for national economic development, welfare, environment development. The purpose of establishing states in its article 1, the law is as follows:

> *The purpose of this Act is to contribute to the preservation of the environment, the sound and sustainable development of the national economy, and the promotion of national welfare by diversifying energy sources through the promotion of technological development, use and distribution of new energy and renewable energy, and the activation of the new energy industry and the renewable energy industry, and by promoting the stable supply of energy, environment-friendly conversion of the energy structure, and the reduction of greenhouse gas emissions (MOTIE, 2014a).*

Therefore, we can say that the policy about new and renewable energy in South Korea is endogenous.

Consistency of government targets

The government extended RPS target that 10 percent of total electricity generation supply by new and renewable energy. The original goal was achieving the target by 2022, however they prolonged the year by 2024 (Lee JH, 2014). In addition, the South Korean government set a distribution rate goal of new and renewable energy as 11 percent by 2030 in the government's first national energy master plan in 2008. However, the achieving year was also changed to 2035 on its second national energy master plan in 2014 (MOTIE 2008; 2014b). The nation set the target of the distribution rate of new and renewable energy among all energy sources as 5 percent by 2011 but the rate was 3.17 percent in 2013 (Lee SH, 2014; Kim JC, 2013)

Longevity of financial political commitments

The budget for new and renewable energy was 11.8 billion won in 2003 and increased by 1 trillion won in 2011 in South Korea. However, the budget was decreased by 14.7 percent (85.12 billion won) in 2013 compared to previous year 2012. The budget was arranged as 80.27 billion won for 2014 decreased 5.7 percent compared to 2013 (Lee SH, 2014). The support for R&D 22 billion won decreased. Even though the total budget was reduced, the direct financial support was increased by 103.4 billion won in 2014 which is 24.2 billion won added compared to 2013. The added budget categories are supporting overseas expansion, energy public relations, and constructing energy storage system fusion complex (Kwon, 2014).

Existence of incentives for stakeholders to comply with policy

The 'Green Home project' that support part of installation fee is based on new and renewable energy facility for residential building. Maximum 2.22 and 2.82 million won can be supported for 2.0 kW and 2.0 kW-3.0 kW solar PV installation capacity. For solar thermal installation, between 3.64 million won and 8.40 million won can be supported depends on installation capacity (KEMCO, 2014b).

On May 2013, MOTIE announced '2013 House supporting project' which support total 15.7 billion won. 1.9 and 7.7 billion won would be provided for solar PV and solar thermal.

Ownership concentration of key industries

During 1969 and 1970, 11 companies among aviation, manufacture, and transportation area such as Korean air line, Korean machinery, and marine-transportation company were privatized and became in the black. KEPCO, POSCO (formerly Pohang Iron and Steel Company), and Kookmin bank sold stocks to public in 1987, Korea Exchange Bank, and Korea Mobile Communication became private enterprises in 1993. After 1998, the government introduced the 'management privatization' and achieved privatization of 8 state owned-enterprises including 67 subsidiary companies such as Korean heavy industry, Korean telecom, and Korean Tobacco Company. (Kim and Lee 2009: 9)

The shareholders of KEPCO consist of 29.94 percent of Korea Finance Corporation, 21.17 percent of Korean government, 23.46 percent of foreigners, and 25.43 percent of ordinary shareholders (KEPCO, 2014c).

Power and organization of the public

Since 1990s, democratization and globalization have led to more individual, social participations and socio-political activities in South Korea. These phenomenon have also influenced the revitalization of non-government or citizen organization. In addition, the advance of telecommunication technology has improved individual communication abilities in society (Cho, 2009).

The citizen's alliance for the general election in 2000 for example shared data for the public, on a candidate's military history, criminal record, and payment of taxes shared. They also had a list including 86 defeated candidates. 59 candidates were defeated in the election among 86. Cho estimates that they accomplished considerable political achievement (Cho, 2009). As we examined, the power of the public opinion is quite high in South Korea.

Results achieved/ anticipated according to the evaluation of other criteria

Chen et al (2014), analyzed renewable energy policies in South Korea with the SWOT analysis. South Korea's economy is highly industrialized and therefore positive synergy effects of high-technology, such as IT and auto manufacturing industry are expected for the renewable energy market. However, the government has set conservative targets for the renewable energy deployment. Also the low domestic electricity prices are considered a weakness.

Chen et al. insist that the establishment of green energy technology and development strategies, as well as developing the second National Energy Basic Plan, will increase opportunities for exports through the Korea-EU FTA. Threats to the development of renewable energies, are the pro-nuclear power development under Park Geun Hye administration; the increase of foreign competition in renewable technology through the Korea-EU Free Trade agreement; and the rising of inexpensive shale gas resources (Chen, 2014).

Political system

In 1987, the political system in South Korea changed from authoritarian to democracy. The current political system in South Korea is a presidential system. Kim argues that issues are being solved by systematic progresses and functions even though many precariousness exists internally and externally in the system (Kim YJ, 2014).

South Korea has a multi-party system. The main parties are the Saenuri (conservatives), the New Politics Alliance for Democracy (Liberals), the Unified Progressive Party, and the Justice Party. The ruling party (Saenuri) holds a majority having 158 seats among 300.

Importance of (renewable) energy to public

As we discussed earlier, South Korea depends on energy import from overseas with more than 90 percent. Energy security is therefore a sensitive issue in South Korea. In September 2011, there has been an incident were the Korea Power exchange blacked out for about 4 hours on national level, due to the lack of backup power. Farm houses of livestock, poultry, and fish farms were damaged and some citizens were stuck in the elevators (Kim, 2013). Therefore, there is a high demand for secured energy supply within the country.

Stage of electoral cycle

South Korea has a presidential system with electoral cycles of five years. The constitution of the Republic of Korea, Article 42 and 70 states that *the term of office of members of the National Assembly shall be four years and the term of office of the President shall be five* *years, and the President shall not be reelected (Constitution of the Republic of Korea, 1984).* As Park, Geun-hye's presidency began on February 2013, it can be concluded that the government is still at a comparatively early stage of the electoral cycle.

Rationale for deploying renewable technologies

Article 1 of the 'Act on the promotion of the development, use and diffusion of new and renewable energy' reads as follows:

> *The purpose of this Act is to contribute to the preservation of the environment, the sound and sustainable development of the national economy, and the promotion of national welfare by diversifying energy sources through the promotion of technological development, use and distribution of new energy and renewable energy, and the activation of the new energy industry and the renewable energy industry, and by promoting the stable supply of energy, environment-friendly conversion of the energy structure, and the reduction of greenhouse gas emissions (MOTIE, 2014a).*

However, President Park's administration announced to add more nuclear plants numbers from present 23 to more than 39 in the National secondary energy basic plan in January 2014 (Hwang, 2014).

Below table is the evaluation of solar energy political viability in South Korea.

Table 84. Evaluation of solar energy political viability in South Korea

Indicators	Evaluation
• Existence of related policy, programs, plans, strategies, laws and activities	o
• Register of stakeholders involved and their official viewpoint	o
• Policy origins: developed internally in response to local ambition, or response to pressures from external bodies	endogenous
• Consistency of government targets	x
• Longevity of financial political commitments	Δ
• Existence of incentives for stakeholders to comply with policy	o
• Ownership concentration of key industries	Some by government
• Power and organization of the public	Quite high
• Results achieved/ anticipated according to the evaluation of other criteria	SWOT analysis available
• Political system	Democratic presidential system, Multi-parties
• Importance of (renewable) energy to public	Energy security, National blackout
• Stage of the electoral cycle	Comparative early
• Rationale for deploying renewable technologies-compatibility or conflicts with other policy priorities	Compatible and conflict with nuclear generation

2.4.5.3. Policy analysis in Japan

In 1964, the MITI introduced the Sunshine project that supports non-fossil energy resources. Thanks to the oil crisis in 1979, the project budget increased by 200 percent compared to initial funding. The Solar PV industry benefits largely from projects by Sharp, Sanyo, and Kyocera Company (Muhammad-Sukki et al. 2014).

In 1992, the net billing program which was the first solar PV related regulation was introduced. The content is that the excessed electricity generation from solar PV is purchased by the utility companies until the purchase rate of retail electricity price is equal (Muhammad-Sukki et al. 2014; Kaizuka, 2012).

A national subsidy program for residential installation of solar PV that supports 50 % of the installation cost was launched in 1994 and ended in 2005. The maximum ceiling price covered max. 900,000 yen per kW at first but diminished to 20,000 yen (Muhammad-Sukki et al. 2014; Myojo and Ohashi, 2012). The program brought 250,000 solar PV installations and reduced the average installation cost from 1,929,000 per kW in 1994 to 661,000 yen per kW in 2005 (Muhammad-Sukki et al. 2014; Foster, 2005).

The RPS was adopted in 2003 in Japan. The percentage which the generation company should purchase from renewables was 1.35 % by 2010. However, the goal could not be achieved and the government introduced FIT in 2009 instead (Muhammad-Sukki et al. 2014). The FIT rate was 42 yen kWh up to 10 kW for 10 years (METI, 2012).

In 2011, the more comprehensive law 'Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities' was adopted owing to the Fukushima disaster (Muhammad-Sukki et al. 2014; Wakabayashi and Katayama, 2012). The target is that 20-35 percent of the energy shall come from renewable energies by 2030. The goal of installation capacity of solar PV is 28 GW by 2020 and 50 GW by 2030 (Muhammad-Sukki et al. 2014; Boone, 2012). 1.7 GW of solar PV was installed in 2012 which means an increase of 33 percent compared to 2010. The total cumulative installation are 6.6 GW in 2012 (Muhammad-Sukki et al. 2014; Yamada and Ikki, 2012).

Existence of related policy, programs, plans, strategies, laws and activities

The goal of the Renewable Electricity Target was set 16 TWh by 2014 in Japan. In this target, geothermal and hydro energy which is the main renewable energy sources in Japan was excluded. Therefore, solar and wind power are considered significant in reaching the goal.

Table 85. Annual renewable electricity utilization targets in Japan (Unit: TWh)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Target	8.34	8.67	9.27	10.33	12.20	13.15	14.10	15.05	16.00

Source: Jordan-Korte (2011); Agency for Natural Resources and Energy (2003)

The Feed-in Tariff Scheme was passed on August 2011 and launched on July 2012 in Japan. The Ministry of Economy, Trade and Industry (METI) explains the regulation as follows:

Under the feed-in tariff scheme, if a renewable energy producer requests an electric utility to sign a contract to purchase electricity at a fixed price and for a long-term period guaranteed by the government, the electric utility is obligated to accept this request (METI, 2011).

In 2012, the Energy and Environment Council set-up the target called 'Innovative Strategy for Energy and the Environment' proposing that of renewable energy should take a share of 30 percent by 2030 (ISEP – Institute for Sustainable Energy Policies, 2013).

Register of stakeholders involved and their official viewpoint

Organizations of renewable energy and solar energy in Japan are: Japan Council for Renewable Energy (JCRE), Japan Renewable Energy Foundation (JREF), Japan Photovoltaic Energy Association (JPEA), and Japan for Sustainability (JFS). The Institute for Sustainable Energy Policies (ISEP) is an academic organization for renewable energy.

JCRE was established in 2007 and performs activities as follows: *International conference held in Japan every four years, International Exhibition every year with renewable forums covering all areas, and in intermediate year of International Conference, support to have conference in Asian country (JCRE, 2014b).* They pursue to cooperate closely not only with industry, academia, and socio-governmental organizations but also with international organizations such as IEA and IRENA.

Founded by Masayoshi Son in 2011, JREF introduced their missions on its web-site as follows: *Establish a society based on renewable energy. Research, develop and advocate policies, measures and financial/business models that are based on the dynamics of markets and society, to promote renewable energy. Build up partnerships and networks with international/domestic organizations and civil societies (JREF, 2014).* They publish proposals and reports for Japan's renewable energy systems and programs.

JPEA was founded in 1987 and the organization aims *to contribute to the prosperity of Japanese economy and the improvement of the national life depending on the establishment and the deployment promotion regarding utilization of the technology of photovoltaic solar power generation system (JPEA, 2014)* They have 11 committees such as technical information, Statistics, and International operation etcetera.

JFS is a non-profit group which provides information about sustainable society in Japan. They deal with topics not only on energy and climate change but also on economy, policy, and technology. In the energy and climate change category, they offer articles about useful renewable energy usages and the current situation in Japan.

Policy origins (endogenous or exogenous)

Many articles related with Japanese energy policy after 2011 begin with an introduction of the Fukushima disaster (ISEP, 2013; McLellan et al. 2013; Tanaka, 2013; Muhammad-Sukki at al. 2014; Huenteler et al. 2012; Esteban et al. 2013). The event had enormous influence on the domestic energy policy and Japan seeks for alternative energies instead of nuclear power.

Jordan-Korte insists that Japan was pressured by 1990s environmental and climate change concerns to develop renewable energy even though the promotion of renewable energy was initially motivated from energy security (Jordan-Korte, 2011).

Therefore, the renewable energy related policies in Japan are regarded as exogenous because of natural disasters and climate changes.

Consistency of government targets

The government targets of renewable energy including solar energy is consistent in Japan. The consistency was examined with the 'National Survey Report Japan' by the IEA. The administration set minimum ration of renewable energy usage by 2010 as 12,200 GWh and 1.35% of net system energy demand. We could see this target has not changed in 2003 and 2006 (Ikki and Tanaka, 2004; Ikki and Matsubara 2007).

The introduction of 4,820 MW of solar PV by 2010 was another set target by the government (Shino and Ikki, 2003). The target has also not changed in the next years report in 2004, but they finally achieved the goal in 2011 (Ikki and Tanaka, 2004; Yamada and Ikki 2013).

The solar PV installation volume target by 2020 is 28 GW and conversions efficiency PV module by 2050 is 40 percent. These goals are continued in the reports in 2011 and 2012 (Yamamoto and Ikki, 2011; Yamada and Ikki, 2012).

Longevity of financial political commitments

As we examined above, the government supports solar PV for residential installation cost by 50 percent since 1994. The subsidy was continued until 2005 (Muhammad-Sukki, 2014).

The FIT scheme began in 2012. In Japan, the tariff for solar PV is 40 yen/ kWh to 42 yen while wind power is 55 yen/ kWh for 20 kW or more and 22 yen/ kWh for less than 10 kW. However, the incentive was reduced by 37.8 yen/ kW in 2013 and by 32 yen/ kW in 2014 (Watanabe, 2013; Colthorpe, 2014).

Table 86. Tariff and duration of solar PV in Japan

Procurement category		10 kW or more	Less than 10 kW (purchase of excess electricity)
Cost	Installation cost	325,000 yen/kW	466,000 yen/kW
	Operating and maintenance costs (per year)	10,000 yen/kW	4,700 yen/kW
Pre-tax IRR (Internal Rate of Return)		6%	3.2%
Tariff (per kWh)		32.0 yen	32.0 yen

Duration	20 years	10 years

Source: METI (2012); Colthorpe (2014)

Thus the financial political commitments for solar energy is steady even though the amount has been reduced.

Existence of incentives for stakeholders to comply with policy

As we explored above, Fee-in Tariff is available in Japan. There is another tax incentive called ‘Green Investment Tax Incentive’ for taxpayers. The taxpayer is able to choose one among following:

1. *30 percent special depreciation in addition to ordinary depreciation*
2. *100 percent depreciation (i.e. total acquisition costs can be expensed upfront.)*
3. *Tax credit (7 percent of acquisition costs, only available for small and medium sized enterprise (SME). SME is a company with its paid-in capital of JPY100 million or less and is not 50 percent or more owned by a large corporation with its paid-in capital of JPY100 million.) (KPMG, 2014)*

Therefore, we concluded that there are incentives for solar energy policy in Japan with these two regulations.

Ownership concentration of key industries

Due to American presence in Japan after the Second World War, there was less possibility to form public enterprises, as in America private enterprises are the dominant form of business, and the feeling against public enterprise was strong (Toyama, 1998). Only a few became state-owned enterprise since World War II: the Japan Railway Group, Nippon Telegraph and Telephone and Japan Tobacco and salt Public Corporation (Sakoh, 1986). In ‘Forbes Global 2000 Firms in 2011’, 260 Japanese companies were listed which is the second largest number only after the United States. However, only one State-Owned Enterprise (SOE) in Japan was listed.

Table 87. Private enterprises and SOEs in China, Japan, Korea, and the United States among Forbes Global 2000 in 2011

Country	Forbes Global 2000 firms, by country	SOEs	SOEs as share of each country’s Global 2000 listed companies
China	117	70	59.83%
Japan	260	1	0.38%
Korea	60	4	6.67%
United States	543	3	0.55%

Source: Kowalski et al. (2013)

The concentration of key industries are held by so called Keiretsu groups, which are large enterprise complexes, that have played a pivotal role in Japan’s economic development since 1950 (Calander, 1993; Grabowiecki, 2006). The ‘Big Six’ (Mitsui, Mitsubishi, Sumitomo, Fuji, Sanwa and Dai-Ichi Kangyo) are commonly mentioned as Keiretsu. The companies established their own bank, trading, steel, manufacturing and other subsidiaries. Keiretsu made up 75 percent of the value of shares at the Tokyo Stock Exchange Market in late 1980 (Lobo, 2012). Keiretsu groups currently, are seeking partnerships with foreign investors and Japanese suppliers (Lobo, 2012).

Power and organization of the public

The nuclear disaster in Fukushima 2011, has led the public to recognize the importance of renewable energy and has become very active. Even though the public had advocated the FIT program before Fukushima, the social activities were few such as single or local events in symposiums. ISEP a Non-governmental organization (NGO), has being working with METI since 2009. Together, they discussed about the FIT framework and delivered the opinion from renewable energy companies (Tominaga, 2014).

Active movements like petition, film, legal action, and national rally dramatically occurred after the event on the national level. 79,000 people have participated in the national rally against nuclear energies on November 6th 2014. Various participants were in action such as lawyer groups, doctor groups, professors, labor unions and religious groups, as well as celebrities, and victims. Tominaga argues that *continued public pressure shifted power dynamics in the parliament from the METI to the government (Tominaga, 2014).*

Results achieved/ anticipated according to the evaluation of other criteria

The 'subsidy for measures to support introduction of residential PV Systems' was introduced in 2008. The objective for this project was the cost reduction of residential PV systems and market expansion. The objectives were individuals or corporate bodies. The subsidy amounted to max. 70,000 yen/kw of PV modules, funded by the Agency for Natural Resources and Energy (ANRE) and METI. JPEA and Japan Photovoltaic Expansion Center (J-PEC) managed the project. 361,711 applications (approximately 1.4 GW) were accepted between 2008 and 2010. The cumulated capacity is about 2.98 GW. This program has stimulated the shrunken residential market and the market grew rapidly (Yamamoto and Ikki, 2011).

In addition, there were more solar PV projects in Japan: the Project for Promoting the Local Introduction of New Energy, Project for Supporting New Energy Operators, and Eco-school Model Promotion Pilot Project (Yamamoto and Ikki, 2011).

Political system

Japan's political system is a multi-party parliamentary representative democratic constitutional monarchy. The Diet is the highest organ of the state power, designated by the constitution. The prime minister is the representative of the Diet (WebJapan, 2013).

Traditionally, the 'iron triangle' which means strong connections among industry, bureaucracy and politics in Japan has influenced domestic policy making. Jordan-Korte states that the voluntary purchase agreement in the early 1990s was able to be established thanks to this deep connections (Jorda-Korte, 2011).

The three main participants (business networks, bureaucracy and government), for establishing renewable energy policy are located in Tokyo. This political and economic power concentration in Tokyo heavily impacts a strong network with frequent meetings (Jordan-Korte, 2011).

Importance of (renewable) energy to public

Japan is vulnerable to natural disasters such as earthquakes and tsunamis. Hence there is a great importance of generating and distributing safe electric power. (Esteban and Portugal-Pereira, 2014, p.761). As quoted many times, an earthquake has struck Fukushipa with a Richterll scale magnitude of 9.0 led to the destruction of the Dai-ich nuclear power plant in March, 2011. As known as well, a person can die within hours depending on the level of radioactivity they are exposed to; also contaminated foods by radioactivity influence the human body. This disaster has severely affected paradigms of Japan's energy policy (Huenteler et al. 2012).

Stage of electoral cycle

There are three types of elections in Japan: the House of Representatives- the lower house (every four years), the House of Councilors – the upper house (every three years), and local elections (every four years) (Alvarez-Rivera, 2013). The prime Minister of Japan is chosen by the National Diet. The election of the Prime Minister is held when the cabinet changes. In December 2012, the 46th general election was held in Japan and Liberal Democratic Party won the election. The electoral cycle of the two chambers of the Diet do not usually occur at the same time.

The changing cabinet influences policies regarding renewable energy in Japan. The 'Green Policy Outline' was prepared in December however, the strategy will be reviewed again because the Prime Minister regime was changed (ISEP, 2013).

Rationale for deploying renewable technologies

The ‘Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities’ was passed in 2011. This procedure happened after the Great East Japan Earthquake. The main content of this Act is that the electricity companies have to purchase electricity generated from renewable energy sources, for example wind, solar, hydro, geothermal, and biomass. METI explains the purpose of this Act as ‘*a scheme to foster renewable energy in Japan with the help of all electricity customers’* (METI, 2011).

Below table is the evaluation of solar energy political viability in Japan.

Table 88. Evaluation of solar energy political viability in Japan

Indicators	Evaluation
• Existence of related policy, programs, plans, strategies, laws and activities	O
• Register of stakeholders involved and their official viewpoint	O
• Policy origins: developed internally in response to local ambition, or response to pressures from external bodies	exogenous
• Consistency of government targets	O
• Longevity of financial political commitments	Δ
• Existence of incentives for stakeholders to comply with policy	O
• Ownership concentration of key industries	Mostly private
• Power and organization of the public	Relatively high
• Results achieved/ anticipated according to the evaluation of other criteria	Stimulated the market
• Political system	Democratic, Prime minister, Multi party
• Importance of (renewable) energy to public	Important due to frequent national disasters
• Stage of the electoral cycle	Middle phase
• Rationale for deploying renewable technologies-compatibility or conflicts with other policy priorities	National energy security

3. Conclusion

The thesis analyzed the solar energy potential in China, South Korea, and Japan by using the framework developed by Kreycik et al. (2010) that indicates four basic dimensions: Resource, Technology, Economy, and Market. By summarizing the above in-depth analysis, this last part of the thesis will answer the research questions:

• How large is the solar energy potential in China, South Korea and Japan?

• What is the theoretical and economic potential of solar energy in East Asia?

• How is the solar energy market situation in East Asia?

Resource potential (Theoretical potential)

The theoretical potential of solar energy was measured in terms of solar radiation quantity in China, South Korea, and Japan, as well as by indicating the amount of sunshine hours.

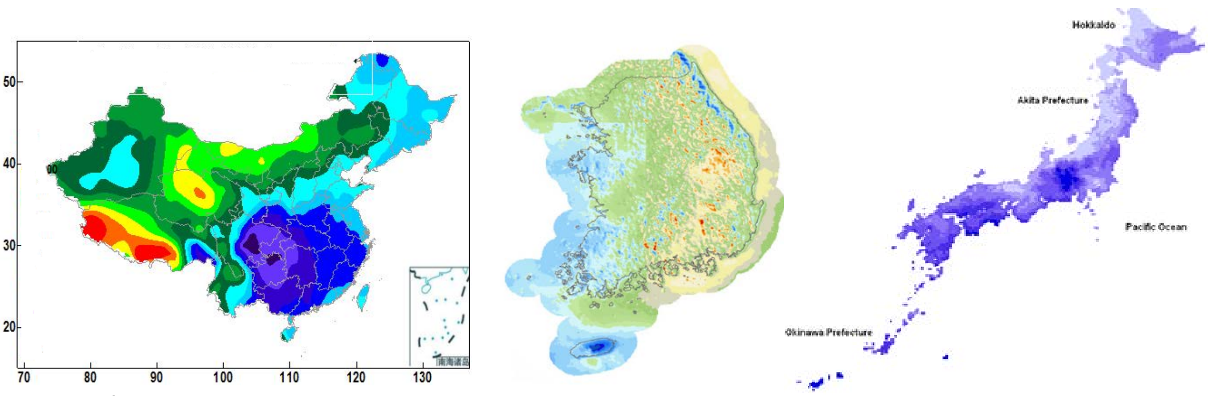
In China, the south-western areas such as Tibet and Qinghai provinces measured the highest solar radiation. Tibet even showed an average radiation of more than 7,911 MJ/m^2 during the period of observation, which is the highest level world-wide. The provinces Tsinghai, Gansu, and Xinjiang also measured significantly high radiation, the average being 6,952, 6,459, 6,342 MJ/m^2 respectively. On the other hand, the south-eastern part of China, like the Chongqing, Sichuan, and Guizhou provinces, or the north-east areas recorded a low level of radiation. Therefore, the most attractive regions for concentrating solar power (CSP) are located in the south-west of China. However, there exists a considerably far distance between the solar-rich areas in the south-west and the electricity-demanding areas specifically at the east-coast.

In South Korea, especially the south-eastern regions show a high resource potential. Interestingly, Mokpo city as an exemption recorded the highest solar radiation of 5,110.39 MJ/m^2, being located on the south-west coast. Jinju was assessed as the city that has the second highest radiation. On the other hand, the north-eastern area and Jeju Island showed relatively low radiation. Measured by month, the solar radiation was recorded highest in May in South Korea.

In Japan, the south-western areas receive higher solar radiation than the north-east. The highest radiations among Japan's cities were recorded in Osaka, Hiroshima, and Kumamoto. Sapporo is assessed as the city receiving lowest radiation.

The maps indicating the radiation in each country are again shown in below figure 38.

Figure 38. Solar radiation in China, South Korea, and Japan



Source: left - CMA wind and solar energy resources center (2011); middle - NIMR (2014); right - CleanBiz.Asia

Examining the sunshine duration distribution, the records go along with the solar radiation distribution.

South-western and central-northern regions of China are exposed to many hours of sunshine, while central and south-eastern areas measured a comparatively low time of sunshine. Unsurprisingly, the capital of Tibet – Lhasa – indicated the highest sunshine duration with an average of 3,123.28 hours per year between 2009 and 2013. The cities Urumqi, Yinchuan, and Xining recorded 2,875.82, 2,740.28, and 2,596.72 hours per year, respectively.

In South Korea, especially the south-eastern areas show high sunshine duration, whereas the capital city Seoul, as well as Chuncheon, Wonju, and Jeju indicate comparatively less hours of sunshine. Incheon, located at the west coast near the metropolitan area of Seoul, recorded 2,305.6 sunshine duration per year in 2008 and thus receives the highest sunshine duration among South Korea's main cities. Second and third are Busan with 2,291.7 hours and Daegu with 2,245.5 hours of sunshine in 2008.

In Japan, the cities of Osaka, Hiroshima, and Kumamoto located in south-west recorded the highest sunshine duration.

Table 89. Average hours of Sunshine duration per year in China, South Korea, and Japan

China			S. Korea		Japan	
City	Province	Hours	City	Hours	City	Hours
Lhasa	Tibet	3,123.28	Incheon	2,305.6	Osaka	2,170.56
Urumqi	Xinjiang	2,875.82	Busan	2,291.7	Hiroshima	2,045.02
Yinchuan	Ningxia	2,740.28	Daegu	2,245.5	Kumamoto	1,963.02
Xining	Qinghai	2,596.72	Cheongju	2,212.1	Nagasaki	1,822.18
Hohhot	Inner Mongolia	2,581.74	Pohang	2,206.1	Tokyo	1,996.10

Source: NBSC (2009-2013); KMA (2008); JMA (2014); Japan statistical yearbook (2014)

Technical potential

The technical potential of solar energy was calculated by taking the reduced amount of the theoretical potential, limited by land use, technical constraints, and solar radiation. More specifically, the technical potential in this thesis is given according to rooftop space per province in China, according to building sites in selected cities of South Korea, and according to buildings in dwellings and non-dwellings in Japan.

Looking at China, the region of Xinjiang shows the highest technical potential with 7,691.87 kWh/yr. Tibet is estimated to have a technical potential of 6,217.11 kWh/yr, and Inner-Mongolia is evaluated with 4644.61 kWh/yr. Not surprisingly, the results are proportional to those areas that have much rooftop space in China.

In South Korea, Seoul ranks number one with a technical potential of 86.53 kWh/yr due to its large area of building sites (=rooftops). Busan, Daegu, and Daejeon are estimated as having a potential of 46.17, 35.82, and 28.38 kWh/yr, respectively; again a consequence of the fact that these are relatively large cities that have much space for installing solar technology.

In Japan, Tokyo was assessed as having the highest technical potential in terms of building areas for dwellings in Japan. Osaka, Kagoshima, Hiroshima, and Kumamoto were calculated as also showing high technical potential.

Table 90. Technical potential in China, South Korea, and Japan

Province	Technical potential of rooftop (GWh/day)	City	Technical potential of building site (GWh/day)	City	Technical potential of building for dwellings (GWh/day)
Xinjiang	115,377.57	Seoul	86.53	Tokyo	187.15
Tibet	93,256.59	Busan	46.17	Osaka	147.33
Inner Mongolia	69,669.10	Daegu	35.82	Kagoshima	128.83
Heilongjiang	27,539.23	Daejeon	28.38	Hiroshima	114.59
Yunnan	27,106.86	Gwangju	24.78	Kumamoto	109.49

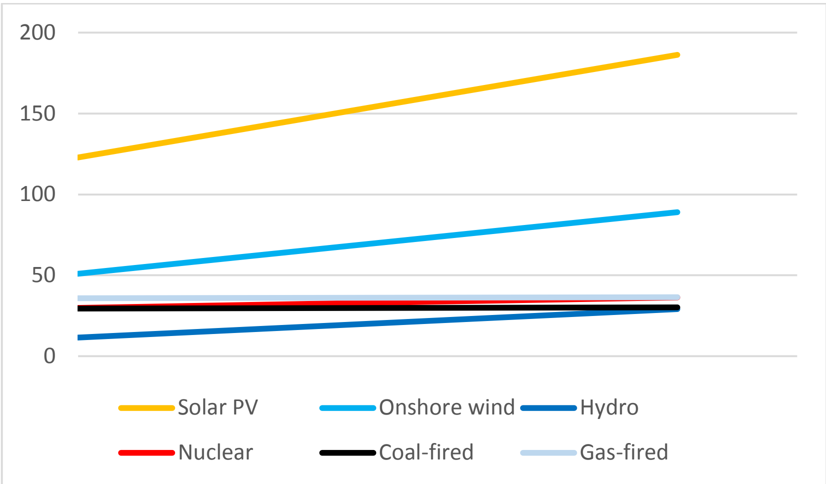
Source: Jo and Kang (2007); China Statistical yearbook (2013); Jo et al. (2012); Ministry of Land, Transport, and Martime (2012); Korea National Statistical Office (2013); NEDO (2013); Japan Statistical Yearbook (2014)

Economic potential

The economic potential of solar energy was defined as the technical potential, taking into account competitive cost levels in comparison to other energy sources. Expressed as the levelized cost of electricity (LCOE), it is a widely used measurement tool comparing the life-cycle costs of generating electricity. As will be shown below, the economic potential of solar PV is still not attractive due to high technology costs.

Looking at the LCOE of energy sources in China, solar PV is yet the most expensive source. The LCOE of solar PV in China is estimated between 186.54 and 272.04 USD/MWh, compared to a relatively low LCOE of other energy sources such as nuclear, coal-fired, and gas-fired electricity (43.72-54.61, 33.26-34.43, and 39.01-39.91 USD/MWh, respectively). Among renewable energy sources, onshore wind technology appears to be also relatively costly. The LCOE of hydro power already shows higher economic potential, however, the costs vary depending on the net capacity. In comparison, the LCOEs of coal-fired, gas-fired, and nuclear power are much more economically competitive. The below figure gives an overview for the LCOE levels China, clearly showing that the LCOE of solar energy is still assessed as the most expensive electricity-generating source:

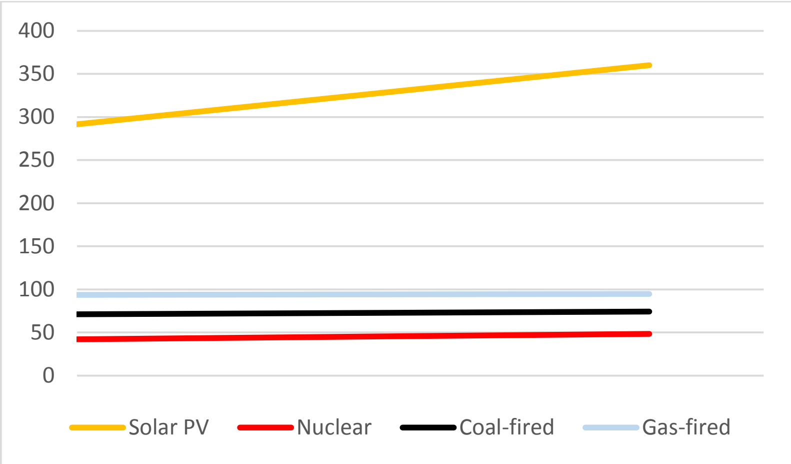
Figure 39. The energy LCOE gaps in China (Unit: USD per MWh)



Source: Own figure based on IEA and OECD (2010)

In South Korea, the LCOE of nuclear electricity shows 42.09-48.38 USD/MWh, being the least expensive source, while that of solar PV is assessed with as much as 338.62-386.06 USD/MWh. In contrast, the LCOE of a coal-fired source of electricity is given with 71.12-74.25 USD/MWh, a gas-fired amounting to 93.63-94.70 USD/MWh.

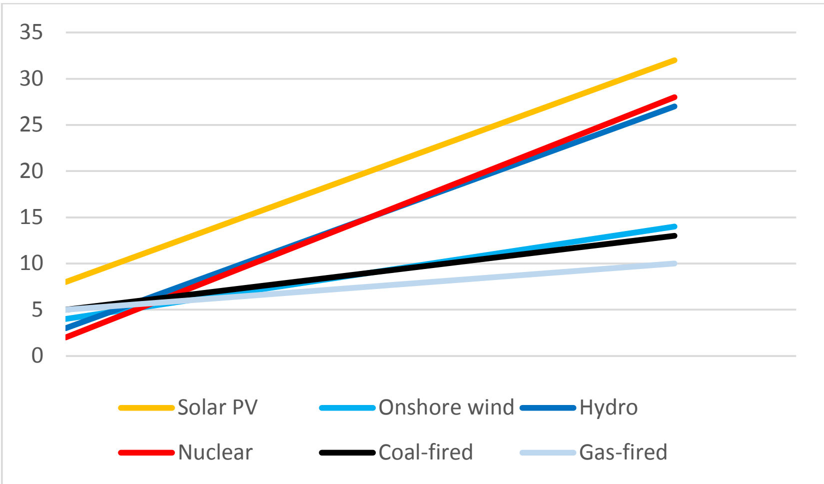
Figure 40. The energy LCOE gaps in South Korea (Unit: USD per MWh)



Source: Own figure based on IEA and OECD (2010); Jeong (2013)

In Japan, the LCOE of solar PV is also the highest among all energy sources. The LCOEs of nuclear and hydro are similar but yet comparatively high. The LCOEs of coal-fired and onshore wind are assessed as pretty economical. The LCOE of gas-fired is the most inexpensive.

Figure 41. The energy LCOE gaps in Japan (Unit: Yen per KWh)



Source: Own figure based on Nakamura (2013)

When evaluating the economic potential of solar energy, Timilsina et al. (2011) took into account climate change cost and concluded that solar energy still needs to become economically more attractive. However, an optimistic argument was presented earlier this year by McKinsey & Company (2014), indicating that the economics of solar power are improving. Key to this potential is said to be sharply declining costs, resulting from steep reductions in upstream costs, chiefly equipment such as module costs, and from downstream costs associated with installation and service. Overall, such cost reductions are likely to strongly increase the competitiveness of solar energy.

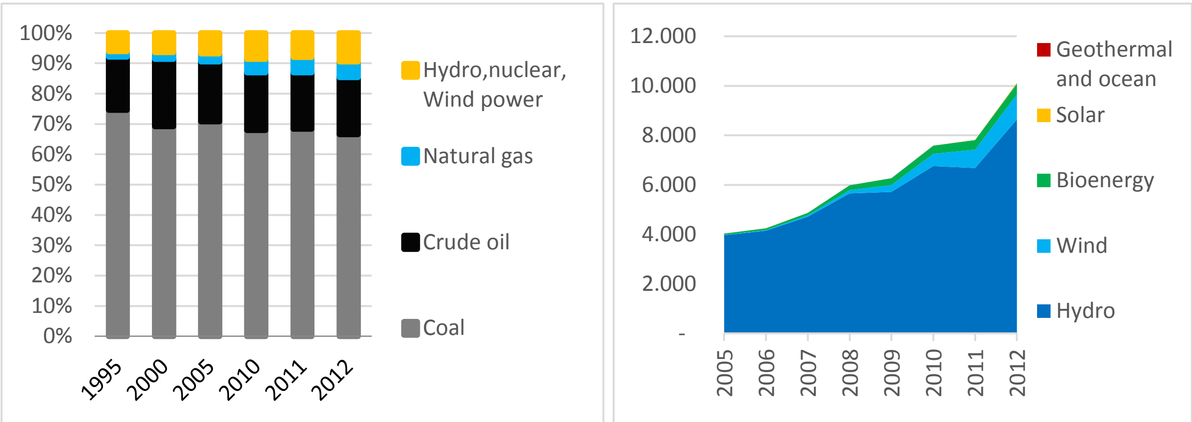
Market potential

The market potential of solar energy was shown first by giving a literature review and overview of the global solar energy market. The analysis then continued with an investigation of demand, supply and market trends in China, South Korea, and Japan, as well as with a comparison of energy prices and introduction of market players. The analysis of the market potential was concluded with a viability analysis of policy measures in the three countries. The most important results are given below.

Energy Market Trends

In China, coal is the most widely used source of energy, consuming 2.4 billion tons of SCE in 2012. This number accounts for about 66.6 % out of all energy sources. In addition, 680.0 million tons SCE of Crude oil (18.8%) were used, as well as 188.1 million tons SCE of Natural gas (5.2%). From renewable energy sources, 340.0 million tons SCE of hydro, nuclear, and wind power (9.4%) were consumed. Looking at renewable electricity generation in China, hydro-power held an absolute majority, generating 864.1 billion kWh in 2012. Solar energy contributed 3.5 billion kWh in 2012; wind, bio-mass, and geothermal energy generated 10.0 billion, 4.4 billion, and 0.01 billion kWh, respectively.

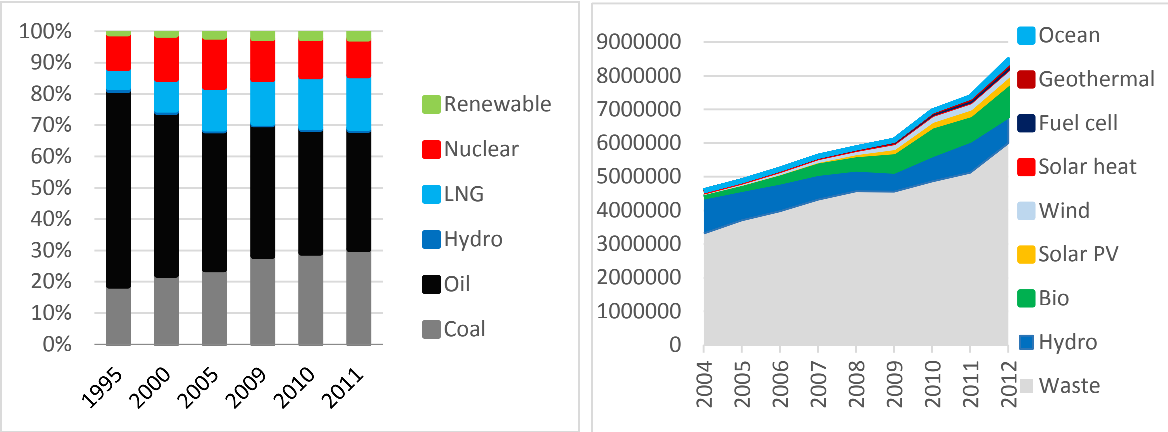
Figure 42. Trend of energy production (%) and renewable electricity generation (100million kWh) in China



Source: NBSC (2013); China Renewable Energy Information Portal (2013)

In South Korea, oil is the most widely used source of energy, with a number of 101.9 million toe, i.e. approximately 38.1 % of the total energy consumption in 2011. In the same year, coal, liquefied natural gas (LNG), and nuclear power amounted to 30.3 %, 16.8 %, and 11.7%, respectively. In South Korea, waste energy is defined as a renewable resource and holds the absolute majority of total renewable energy production in South Korea. In addition, 814,933 toe of hydro-energy and 965,363 toe out of bio-mass were produced. The Solar PV panels generated 237,543 toe, wind energy a number of 192,674 toe.

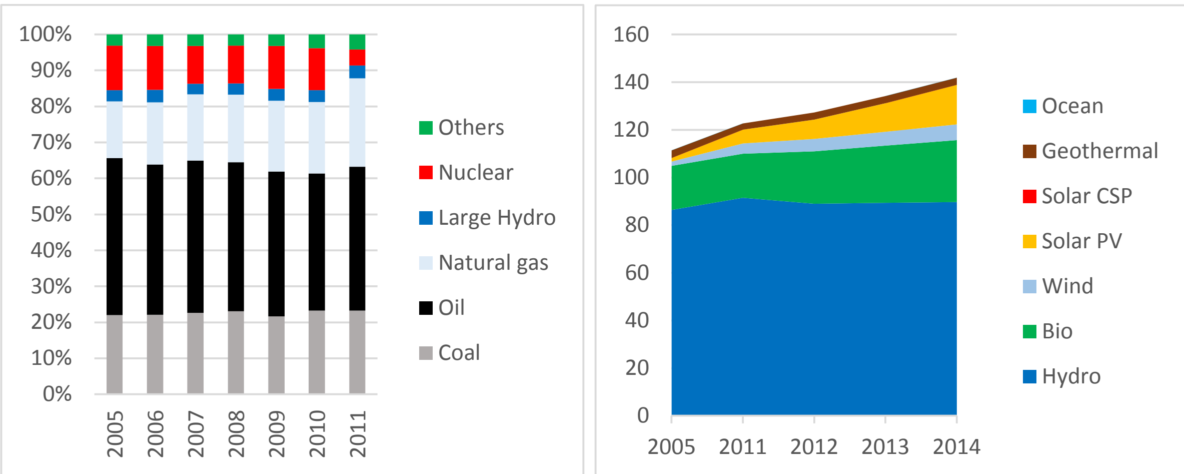
Figure 43. Trend of energy consumption (%) and new and renewable energy production (toe) in South Korea



Source: MKE and KEEI (2012); KEMCO (2013)

In Japan, coal, oil, and natural gas are the most important energy sources, showing 23.3, 39.9, and 24.6 percent of energy supply in 2011. The supply of nuclear power decreased dramatically to 4.4 percent in 2011, in favor of other energy sources that took up 4.2 percent. Looking at renewable electricity generation, hydro power was the majority energy source generating 66.7 percent in 2013. Bio mass, wind-, geothermal power accounted for 17.9, 4.3, and 2.2 percent, respectively. The percentage of solar PV generation has increased by 9 percent. Overall, solar energy still accounts for a minority position in terms of energy use in all three countries, but shows the highest potential in Japan in relative terms.

Figure 44. Trend of energy supply (%) and renewable electricity generation (TWh) in Japan



Source: Japan statistical yearbook (2014); IEA (2012b)

Energy Prices

Among the three analyzed countries, energy prices are generally the lowest in China, except for coal which is cheapest in Japan. The gasoline price is the cheapest in China (1.25 USD/L), while the gas and electricity prices vary depending on the region in that country. The energy prices in South Korea are on the highest levels among the three countries, whereas the electricity price in that nation was comparatively low. While coal was cheapest in Japan, electricity is most expensive in this country.

Table 91. Price of energy in China, South Korea, and Japan (Unit: USD)[48]

		China	*South Korea*	*Japan*
Sources		*2014*	*2012*	*2012*
Oil	Gasoline(L)	1.25	1.87	1.37
	Kerosene(L)	-	1.32	0.86
	Diesel(L)	-	1.70	1.19
Coal/ton		162.23 (as of 2014)	134.18	112.21
Gas/m^3		0.78-0.21 (as of 2011)	0.80	0.63
Electricity/kWh		0.11-0.07 (as of 2012)	0.10	0.19

Source: Own compilation based on LBNL (2012); Song (2013) KEMCO (2014a); IEA (2014); Ecodb (2014)

Market Players

Product Specifications: Table 92 shows an overview of the product specifications of each market player introduced in the analysis. In fact, there is not much difference among the efficiencies of solar modules based on poly-crystalline silicon. The most efficient products are delivered by JinkoSolar (16.50 percent efficiency) and Hanwha SolarOne (16.4 percent efficiency). What is more, maximum power and efficiency positively correlate: the higher the maximum power of the product, the higher the efficiency. Looking at the warranty of solar modules, Hanwha SolarOne and Hanwha Qcells give a 12-year product warranty, while the other companies have 10-year guarantee.

Table 92. Product specification based on poly-crystalline silicon technology

Company	Production name	Maximum power-Pmax (W)	Efficiency	Dimensions (mm)	Weight (kg)	Warranty
Yingli	YGE 60 Cell Series	240-260	14.7-15.9	1650*900*40	18.5	10-year limited product warranty
Trina solar	PD05	245-260	15.0-15.9	1650*992*35	18.6	10 year product warranty, 25 year linear power warranty
JinkoSolar	JKM265P-60	245-265	14.97-16.19	1650*992*40	18.5	10-year product warranty, 25 year linear power warranty
	JKM270PP-60	255-270	15.58-16.50	1650*992*40	18.5	
Hanwha SolarOne	HSL 60 Poly	240-265	14.8-16.4	1636*988*40	19±0.5	12 year product warranty, 25 year linear performance warranty
Hanwha Qcells	Q.PRO BLK-G3	245-265	14.7-15.9	1670*1000*35	19	Invest security due to 12-year product

[48] given in USD at exchange rates per 1USD=1,051.4Kwon=0.94JPY=0.16RMB as of 22 October 2014

	245-265					warranty and 25-year linear performance warranty
Sharp	ND-R245A6	245	14.9	1652*994*46	19	10-year product guarantee, 25-year linear performance guarantee
	ND-R250A5	250	15.2	1652*994*46	19	
Kyocera	KD245GH-4FB2	245	14.8	1662*990*46	20	10 years on 90% and 25 years on 80 % of the minimally specified power P under standard test conditions
	KD250GH-4FB2	250	15.1	1662*990*46	20	
	KD255GH-4FB2	255	15.4	1662*990*46	20	

Source: Yingli (2014); Trina solar (2014a); Jinko Solar (2014a); OCI (2014); Hanwha SolarOne (2014a); Hanwha Qcells (2014); Sharp UK (2014); Kyocera solar Europe (2014)

Financial Statements: table 93 below summarizes the financial statements of 2013 per market player. Due to an obviously difficult market situation, many of them could not operate profitably in that year. Only JinkoSolar and Kyocera recorded a positive net income.

Table 93. Financial statement of companies in 2013 in China, South Korea, and Japan[49]

	Yingli	Trina solar	JinkoSolar	OCI	Hanwha SolarOne	Sharp	Kyocera
Total net revenues (Thousand USD)	2,185,682	1,774,971	1,153,077	2,773,346	769,771	23,271,026	12,018,211
Operating profit (loss) (Thousand USD)	(182,174)	(38,080)	105,154	(99,484)	(66,255)	(1,373,266)	722,245
Net income (loss) (Thousand USD)	(334,723)	(72,236)	30,625	(270,296)	(142,381)	(5,120,171)	632,347

Source: Yingli (2014); Trina solar (2014a); Jinko Solar (2014a); OCI (2014); Hanwha SolarOne (2014a); Hanwha Qcells (2014); Sharp UK (2014); Kyocera solar Europe (2014)

Viability Analysis of Policy Framework

The most common policy-measures influencing the renewable energy market are the Renewable Portfolio Standard (RPS) and the Feed-in Tariff (FIT). The solar energy policy viability (or feasibility) in China, South Korea, and Japan was analyzed with the indicators provided by IRENA. The three countries satisfy the first indicator ‘Existence of related policy, programs, plans, strategies, laws and activities and the second ‘Register of stakeholders involved and their official viewpoint’. The policy origins are endogenous in China and South Korea but exogenous in Japan. The government’s target of solar energy is consistent in China and Japan but not in South Korea. Even though there are continuous financial commitments for renewable energy, the supporting amounts have actually been reduced in all three countries. On the other hand, all countries fulfill the indicator ‘existence of incentives for stakeholders to comply with policy’.

Regarding the ownership of key industries, many of the important companies are owned by the government in China, and some of them in South Korea. In Japan, most companies are private. The power and organization of the public is weak in China, in contrast to South Korea and Japan. China and Japan were estimated as having satisfactory ‘Evaluation results from other

[49] Exchange rate: 1 USD = 1,065.5 Kwon = 106.51 JPY = 6.14 RMB

criteria' while South Korea shows strong and weak points, opportunities and threats at the same time.

The political system of China is based on communism and a single-party system, whereas South Korea and Japan have a democratic multi-party system. The current stage of the electoral cycle is early in China and South Korea, and in the middle of the phase in Japan. The reasons for fostering renewable energy differ in each country: In China, it is important for the public because of its growing economy, South Korea needs energy security, and Japan focuses on renewable energy owing to frequent natural disaster. The renewable energy technology deployment has less compatibility or conflicts with other policy priorities in China and Japan however, South Korea's renewable energy policy needs to become compatible and reduce the conflict with nuclear power generation.

Table 94. Solar energy policy viability in China, South Korea, and Japan

Indicators	China	South Korea	Japan
• Existence of related policy, programs, plans, strategies, laws and activities	O	O	O
• Register of stakeholders involved and their official viewpoint	O	O	O
• Policy origins: developed internally in response to local ambition, or response to pressures from external bodies	endogenous	endogenous	exogenous
• Consistency of government targets	O	X	O
• Longevity of financial political commitments	Δ	Δ	Δ
• Existence of incentives for stakeholders to comply with policy	O	O	O
• Ownership concentration of key industries	Many by government	Some by government	Mostly private
• Power and organization of the public	Weak	Quite high	Relatively high
• Results achieved/ anticipated according to the evaluation of other criteria	Satisfactory	SWOT analysis available	Stimulated the market
• Political system	Communism but more decentralized than before reformation	Democracy, Presidency, Multi party	Democracy, Prime minister, Multi party
• Importance of (renewable) energy to public	Growing economy, the most electricity consuming country	Energy security, National blackout	Important due to frequent natural disaster
• Stage of the electoral cycle	Comparatively early	Comparative early	Middle phase
• Rationale for deploying renewable technologies- compatibility or conflicts with other policy priorities	Green economy development	Compatible and conflict with nuclear generation	National energy security

Source: own compilation. O is confirmed, Δ is partly confirmed, and X is not satisfactory

Discussion

Focusing on the four dimensions of analysis, the research questions can be answered by summarizing the results as follows:

Among the three countries, China shows the highest resource potential in terms of solar radiation. Among Chinese cities, Lhasa, Urumqi, and Yinchuang rank first when measuring sunshine hours per year. In South Korea, the two provinces Gyeongsangbuk and Gyeongsangnam indicate the highest solar radiation in relation to the rest of South Korea. Among Korea's major cities, Incheon, Busan, and Daegu recorded the highest amount of sunshine hours per year. In Japan, the south-western areas receive higher solar radiation than the north-east. The highest radiations among Japan’s cities were recorded in Osaka, Hiroshima, and Kumamoto. Sapporo is assessed as the city receiving lowest radiation.

The technical potential was calculated by referring to the potential roof top area in Chinese provinces and to the potential surface useable for PV-modules on building sites in South Korean and Japanese cities. Results show that the Chinese provinces Xinjiang, Tibet, and Inner Mongolia have a large technical potential with respect to the area size. Seoul, Busan, and Daegu were calculated to have the highest technical potential regarding useable building sites among South Korean cities. In Japan, Tokyo was assessed as having the highest technical potential in terms of building areas for dwellings in Japan.

Looking at the economic potential, solar energy still appears unattractive in terms of LCOE compared to conventional energies and to renewable energy sources, even if climate change cost are included in the calculation. However, costs for the provision of solar energy are likely to decrease, raising the overall competitiveness of this technology.

Lastly, the market potential shows that solar energy still constitutes for a minority with respect to total energy consumption and renewable electricity generation in all three countries. However, it is revealed that companies are already gaining much profit out of solar energy related products reflecting a growing market. There are also positive signs of fostering solar energy in China, South Korea, and Japan on policy level.

In conclusion, China indeed has great potential of resources and technical capacity, as well as a supportive policy framework. However, the regions that receive high solar radiation are distant from the regions of high energy demand, a challenge which has to be faced. Overall, one can expect that solar power provision in China will continue to be developed, seeing that this sector receives strong government support. South Korea and Japan are geographically less favored than China, which is why, first, it is suggested to enhance the economic and market potential, and second, to develop a policy framework that is more supportive of high-end solar energy technology.

Overall, the purpose of this thesis was to show the potential of solar energy provision in China, South Korea, and Japan, as academic research on solar energy lacks an in-depth analysis using multiple dimensions. This thesis focused on three economically strong countries in East Asia to fill this gap and specifically add to scientific discourse by having investigated four dimensions of analysis on presumably the most important source of renewable energy.

Future research may scrutinize the above criteria in more detail, and include other countries. After all, energy security, climate change, and environmental problems are not only issues in three countries, but constitute a world-wide challenge. The continuous development of solar power energy requires much more effort from entrepreneurs, policy makers, and scholars indeed.

References

Agency for Natural Resources and Energy (2003) Outline of the PRS System. http://www.rps.go.jp/RPS/new-contents/top/toplink-english.html [retrieved on 13 October 2014]

AHN Joongha (2013) A Study on Optimal Allocation of Energy Sources for Sustainable Development: Focus on Electricity Industry. Seoul National University. Ph.D. Dissertation.

AKPABIO Louis E, ETUK Sunday E. (2003) Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria. Turkish Journal of Physics, vol.27, Issue 2, p.161-167

ALVAREZ-RIVERA Manuel (2013) Election Resources on the Internet: Parliament Elections in Japan, Parts I and II. http://www.electionresources.org/jp/#ASPECTS [retrieved on 13 October 2014]

ARDANI Kristen, MARGOLIS Robert (2011) 2010 Solar Technologies Market Report. U.S. Department of Energy. Energy Efficiency & Renewable Energy. http://www.nrel.gov/docs/fy12osti/51847.pdf [retrieved on 09 April 2014]

ARVIZU Dan, BALAYA Palani, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, R. Zilles (2011) "Direct Solar Energy." In IPCC (Intergovernmental Panel on Climate Change) Special Report on *Renewable energy sources and climate change mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G.Hansen, S. Schlömer, C. v. Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. P.333-400

Avlite (2014) Alphabetical links to Irradiation Data Charts by country.

http://www.avlite.com/technical/solar_chart.php [retrieved on 23 March 2014]

BAKER Erin, FOWLIE Meredith, LEMOINE Derek, REYNOLDS Stanley S. (2013) The Economics of Solar Electricity. Berkeley, California. Energy Institute at Haas.

BesTan (2014) The most expensive gasoline price country in the world. http://bestan.tistory.com/265 [retrieved on 01 October 2014]

Bloomberg (2014) Gasoline Prices by Country. http://www.bloomberg.com/visual-data/gas-prices/20142:China:USD:l [retrieved on 01 October 2014]

BOONE Cathy (2012) Japan's Solar Market Poised for Return to Elite Status. Renewable energy world; 2012. http://www.renewableenergyworld.com/rea/news/article/2012/06/japans-solar-market-poised-for-return-to-elite-status [retrieved on 02 July 2014]

Brundtland Commission (1987) Report of the World Commission on Environment and Development. United Nations.

CALANDER K.E (2005) Strategic Capitalism: Private Business and Public Purpose in Japanese Industrial Finance. Princeton: Princeton University Press.

CAMBELL Matt (2008) The Drivers of the Levelized Cost of Electricity for Utility-Scale Photovoltaics. SunPower Corporation. http://large.stanford.edu/courses/2010/ph240/vasudev1/docs/sunpower.pdf [retrieved on 12 May 2014]

CAMPBELL Richard J. (2014) China and the United States- A Comparison of Green Energy Programs and Policies. Congressional Research Service. Washington, DC.

CHEN Cheng, HUBBARD Michael (2012) Power relations and risk allocation in the governance of public private partnerships: A case study from China. Policy and Society 31 (2012) 39-49.

CHEN Wei-Ming, KIM Hana, YAMAGUCHI Hideka (2014) Renewable energy in eastern Asia: Renewable energy policy review and comparative SWOT analysis for promoting renewable energy in Japan, South Korea, and Taiwan. Energy Policy (2014).

China Renewable Energy Information Portal [中国可再生能源信息网](2013) China Renewable Electricity Generation. http://en.cnrec.info/tools/2013-02-04-461.html [retrieved on 26 April 2014]

Chinese constitution (2004) Chinese government's official web portal. http://english.gov.cn/2005-08/05/content_20813.htm [retrieved on 10 July 2014]

CHO Seok-Jang (2009) Internet based political participation and democracy in Korea – Focusing on impacts on participatory democracy and representative democracy-. Hanyang University. Ph.D. Dissertation.

CIA-Central Intelligence Agency (2014) The World Factbook. Country comparison: Crude oil-Imports. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2243rank.html [retrieved on 10 June 2014]

CleanBiz.Asia (2014) Japanese solar radiation levels. http://www.cleanbiz.asia/image/japanese-solar-radiation-levels [retrieved on 20 May 2014]

CMA wind and solar energy resources center (2011) China solar radiation yearly gross quantity 1978~2007. http://cwera.cma.gov.cn/Website/index.php?WCHID=2 [retrieved on 24 March 2014]

COLTHORPE Andy (2014) Japan's 2014 FiT rates confirmed. PVtech. http://www.pv-tech.org/news/japans_2014_fit_rates_confirmed [retrieved on 13 October 2014]

Constitution of the Republic of Korea (1984) Constitutional court of Korea. http://www.ccourt.go.kr/home/att_file/download/Constitution_of_the_Republic_of_Korea.pdf. [retrieved on 10 July 2014].

CREIA – Chinese Renewable Energy Industries Association (2012) Introduction of the Chinese Renewable Energy Industry Association. http://www.creia.net/aboutus/enintro/index.html [retrieved on 23 June 2014]

DART – Data Analysis, Retrieval and Transfer System (2014) OCI. Quarterly report as of 15th May, 2014. http://dart.fss.or.kr/dsaf001/main.do?rcpNo=20140515000734 [retrieved on 15 July 2014]

DEFAIX P.R, VAN SARK W.G.J.H.M, WORRELL E, DE VISSER E. (2012) Technical potential for photovoltaics on buildings in the EU-27. Solar Energy Vol: 86, Issue: 9, p2644-2653

Ecodb (2014) Trends of natural gas price. http://ecodb.net/pcp/imf_group_ngas.html [retrieved on 20 October 2014]

EIA-U.S Energy Information Administration (2014a) China-Country Analysis Brief Overview. http://www.eia.gov/countries/country-data.cfm?fips=CH

[retrieved on 19 May 2014]

EIA (2014b) China-Analysis http://www.eia.gov/countries/cab.cfm?fips=CH [retrieved on 23 May 2014]

EIA (2014c) International Energy Statistics http://www.eia.gov/countries/data.cfm [retrieved on 23 May 2014]

EIA (2014d) Japan-Analysis http://www.eia.gov/countries/cab.cfm?fips=JA [retrieved on 10 June 2014]

EIA (2014e) Korea, South-Analysis. http://www.eia.gov/countries/cab.cfm?fips=KS [retrieved on 10 June 2014]

Energy use calculator (2014) Global electricity prices. http://energyusecalculator.com/global_electricity_prices.htm

[retrieved on 01 October 2014]

EPIA – European Photovoltaic Industry Association and Greenpeace (2011) Solar generaton 6: solar photovoltaic electricity empowering the world. USA.

EPRC -Electricity Industry Policy Research Center 전력산업연구센터 (2012) 2012 전력 에너지 주요통계 [Electricity Energy statistics 2012]. Uiwang. EPRC.

EPSIS –Electric Power Statistics Information System (2013) Generation quantity by country. https://epsis.kpx.or.kr/ [retrieved on 12 June 2014]

EPSIS (2014) New and renewable energy unit cost. https://epsis.kpx.or.kr/

[retrieved on 09 October 2014]

ESTEBAN Miguel, PORTUGAL-PEREIRA Joana (2014) Post-disaster resilience of a 100% renewable energy system in Japan. Energy 68 (2014) 756-764

EYER Jim, COREY Garth (2010) Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide. A Study for the DOE Energy Storage Systems Program. Sandia National Laboratories. New Mexico, California.

FADEL M. El, RACHID G., EL-SAMRA R., BOU BOUTROS G., HASHISHO J. (2012) Emissions reduction and economic implications of renewable energy market penetration of power generation for residential consumption in the MENA region. Energy Policy 52 (2013) 618-627

FAROOQ Muhammad Khalid, KUMAR S. (2013) An assessment of renewable energy potential for electricity generation in Pakistan. Renewable and Sustainable Energy Reviews. 20 (2013) 240-254.

FOSTER Robert (2005) Japan photovoltaics market overview. Sandia National Laboratory, US Department of Energy; 2005.pp.1-36.

FTHENAKIS Vasilis, MASON James E., ZWEIBEL Ken (2009) The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. Energy Policy 37 (2009) 387-399.

GAUDIANA Russel (2010) Third-Generation Photovoltaic Technology – The Potential for Low-Cost Solar Energy Conversion. The Journal of Physical Chemistry Letters. 2010. 1288-1289.

Google finance (2014) NYSE:JKS. Jinko Solar Holding Co., Ltd. http://www.google.com/finance?q=NYSE:JKS&fstype=ii [retrieved on 23 July 2014]

GRABOWIECKI Jerzy (2006) Keiretsu groups: Their Role in the Japanese Economy and a Reference Point (or a paradigm) for Other Countries. Institute of developing economies. Japan external trade organization. Chiba.

GUO Di, QU, Xiaobo, HUANG Lianfen, YAO Yan (2011) Sparsity-Based Spartial Interpolation in Wireless Sensor Networks. Sensors, Vol: 11 Issue 3, p.2385-2407

Hanwha Chemical (2013) Hanwha Chemical Sustainability Report 2013. Hanwha Chemical. Seoul. http://hcc.hanwha.co.kr/promote/data.jsp [retrieved on 15 July 2014]

Hanwha Chemical (2014) Hanwha Chemical Sustainability Report 2014. Hanwha Chemical. Seoul. http://hcc.hanwha.co.kr/promote/data.jsp [retrieved on 15 July 2014]

Hanwha SolarOne (2014a) Hanwha SolarOne Annual and Transition Report. Edgar online. 2014. New York; Rockville.

Hanwha SolarOne (2014b) Hanwha SolarOne. Production introduction. http://www.hanwha-solarone.com/kr/products [retrieved on 16 July 2014]

Hanwha Qcells (2014) Hanwha Qcells. Products. http://www.q-cells.com/en/products.html [retrieved on 16 July 2014]

HERMANN Weston A. (2006) Quantifying global exergy resources. Journal of Energy. Vol 31, Issue 12, September 2006, Pages 1349-1366

HOOGWIJK Monique (2004) On the global and regional potential of renewable energy sources. Utrecht University. ISBN: 90-393-3640-7

HOOGWIJK Monique and GRAUS Wina (2008) Global potential of renewable energy sources: a literature assessment. Utrecht, ECOFYS.

HUENTELER Joern, SCHMIDT Tobias S., KANIE Norichika (2012) Japans's post-Fukushima challenge – implications from the German experience on renewable energy policy. Energy Policy 45 (2012) 6-11

HWANG Boyeon (2014) Korea and China have the preoccupation with nuclear generation. This is very exceptional in the world. The Hankyoreh. http://www.hani.co.kr/arti/international/america/620423.html [retrieved on 14 October 2014]

IEA - International Energy Agency (2008) Renewables Information 2008 edition. IEA, OECD - Publishing, Paris.

IEA and OECD (2010) Projected Costs of Generating Electricity. OECD/IEA, Paris.

IEA (2011a) Solar Energy Perspectives. OECD/IEA, Paris.

IEA (2011b) Renewable Energy Policy: Considerations for Deploying Renewable. OECD/IEA, Paris.

IEA (2012a) World Energy Outlook 2012. OECD/IEA, Paris.

IEA (2012b) Renewable energy Medium-term Market Report. OECD/IEA, Paris.

IEA (2012c) Electricity information. OECD/IEA, Paris.

IEA (2013) Key World Energy Statistics. OECD/IEA, Paris.

IEA (2014) Energy prices and taxes. OECD/IEA, Paris.

IEA-PVPS (2014) PVPS Report Snapshot of Global PV 1992-2013. IEA-PVPS T1-24:2014.

IKKI Osamu, MATSUBARA Koji (2007) National Survey Report Japan 2006. IEA PVPS & RTS Corporation.

IKKI Osamu, TANAKA Yukao (2004) National Survey Report Japan 2003. IEA PVPS & RTS Corporation, NEDO.

IRENA– International Renewable Energy Agency (2012) Renewable Power Generation Costs in 2012. An Overview. IRENA. Abu Dhabi.

IRENA (2014) Evaluating Renewable Energy Policy: A review of Criteria and Indicators for Assessment. IRENA. Abu Dhabi.

ISEP – Institute for Sustainable Energy Policies (2013) Renewables 2013 Japan status report. ISEP. Tokyo.

Japan Statistical Yearbook (2014) 日本統計年 鑑 2014. Statistics Bureau, Ministry of Internal Affairs and Communications. Tokyo. http://www.stat.go.jp/english/data/nenkan/ [retrieved on 13 August 2014]

Japanese Law Translation (2009) Act on the Promotion of New Energy Usage. http://www.japaneselawtranslation.go.jp/law/detail/?ft=1&ky=%E6%96%B0%E3%82%A8%E3%83%8D%E3%83%AB%E3%82%AE%E3%83%BC%E5%88%A9%E7%94%A8&co=01&x=40&y=19&page=1&re=02 [retrieved on 05 August 2014]

JCRE – Japan Council for Renewable Energy (2014a) Subject to Renewable Energy. http://www.renewableenergy.jp/council/english/renewableenergy.html

[retrieved on 05 August 2014]

JCRE (2014b) What's JCRE. http://www.renewableenergy.jp/council/english/about_jcre.html#section5

[retrieved on 02 July 2014]

JEONG Jong-chul (2012) 태양에너지 가용잠재량 자원지도 분석(The Analysis of a Potential Solar Energy Resource Map. Journal of Environmental impact assessment). The journal of Environmental Impact Assessment Vol.21, No.4, pp.573-579

JEONG Yoonkyung 정윤경 (2013) 태양광 산업 및 모듈가격 전망과 대내외 대응전략 연구 (Future module prices and analysis of domestic and international solar market and industry trends). Korea Energy Economics Institute. Research report 13-21.

Jinko Solar (2010) Annual report 2010. Jinko Solar. Shanghai.

Jinko Solar (2014a) Products. http://www.jinkosolar.com/product.html?lan=en [retrieved on 24 July 2014]

Jinko Solar (2014b) Investor Relations. AGM Summary. Jinko Solar. Shanghai.

JMA – Japan Meteorological Agency (2014) Historic Monthly Values http://www.data.jma.go.jp/obd/stats/etrn/view/monthly_s3_en.php?block_no=47401&view=11 [retrieved on 20 May 2014]

JO Dok-ki, KANG Young-Heack (2006) 국내 고집광 태양에너지 이용시스템 설치를 위한 법선면 직달일사량과 청명일 정밀조사 (A detailed Survey of Direct Normal Radiation and Clear-day for the Construction of Solar Concentrating System in Korea) Journal of the Korean Solar Energy Society. Vol.27, No.3, 2006

JO Dok-ki, KANG Young-Heack (2007) 인공위성을 이용한 동북아시아 지역의 태양광자원 정밀조사 –중국지역 분석을 중심으로 (A Detailed Survey of solar Energy Resources in East-North Asia Areas Using a Satellite-Focused on the Analysis of Chinese Areas) Journal of the Korean Solar Energy Society. Vol.27, No.3

JO Dok-ki, KANG Young-Heack (2008a) 동북아시아 지역의 태양광자원 분석 평가 (Evaluation of Solar Energy Resources in East-North Asia Areas). KSEA (Korean Solar Energy Society) 2008 Spring Annual Conference. 2008-04

JO Dok-ki, KANG Young-Heack (2008b) 국내 고집광 태양에너지 이용시스템 설치를 위한 법선면 직달일사량과 청명일 정밀조사 (A Detailed Survey of Direct Normal Radiation and Clear-day for the Construction of Solar Concentrating System in Korea). Journal of the Korean Solar Energy Society. Vol.26, No.3

JO Dok-Ki, YUN Chang-Yeol, KIM Kwang-Deuk, KANG Young-Heack (2011) 인공위성을 이용한 국내 일사량 분포 예측 (Estimation of Solar Radiation Distribution in Korea using a Satellite). Journal of the Korean Solar Energy Society. Vol.31, No.2, 2011

JO Dok-Ki, YUN Chang-Yeol, KIM Kwang-Deuk, KANG Young-Heack (2012) A Study on the Estimating Solar Radiation in Korea Using Cloud and Hours of Bright Sunshine. Journal of the Korean Solar Energy Society. Vol.32, No.2, 2012

JOHANNSON Thomas B., McCORMIC Kes, NEIJ Lena, TURKENBURG Wim (2004) The potentials of Renewable Energy. International Conference for Renewable Energies, Bonn 2004.

JORDAN-KORTE Katrin (2011) Government Promotion of Renewable Energy Technologies. Policy Approaches and Market Development in Germany, the United States, and Japan. Gabler research. University of Berlin.

JPEA – Japan Photovoltaic Energy Association (2014) Outline of association. http://www.jpea.gr.jp/en/outline/index.html [retrieved on 02 July 2014]

KAIZUKA I. (2012) Net billing schemes, experience from Japan - evolution to net export FiT. PVPS workshop, Frankfurt, Germany; 2012. pp. 1-20.

KANG Hyun Woo (2014) Hanwha group, Hanwha Qcell, Hanwha solarone lead global solar PV market. Korean economy newspaper. http://www.hankyung.com/news/app/newsview.php?aid=2014061861341 [retrieved on 15 July 2014]

KANG Young-Heack (2008) 태양열에너지 기술개발 현황 및 전망 (Current situation and prospect of solar energy technology development). KSEA 2008 autumn.

KEEI – Korea Energy Economics Institute [에너지 경제 연구원] (2013) Energy Info. Korea

KEMCO – Korea Energy Management Corporation [에너지관리공단] (2008) 신재생에너지 RD&D 전략 2030 시리즈 9 태양광 (New and renewable energy RD & D strategy 2030,9: Solar energy). KEMCO. Yongin

KEMCO (2010) 신재생에너지 백서 2010 (2010 Renewable energy whitepaper). KEMCO. Yongin.

KEMCO (2013) 2012 년 신 재생에너지 보급통계(New and renewable supply statistics 2012). KEMCO. Yongin.

KEMCO (2014a) 에너지통계 핸드북 (Energy statistics handbook 2014). KEMCO. Yongin.

KEMCO (2014b) The project for residential. Greenhome. http://greenhome.kemco.or.kr/ext/itr/intr/greenHomeIntro.do [retrieved on 14 July 2014]

KEPCO – Korea Electronic Power Corporation [한국전력공사](2014a) Business, Nuclear http://www.kepco-enc.com/English/sub.asp?Mcode=B010020 [Retrieved on 08 March 2014]

KEPCO (2014b) The monthly report on major electric power statistics 424th. KEPCO. Seoul.

KEPCO (2014c) Company introduction. http://cyber.kepco.co.kr/kepco/KE/B/htmlView/KEBAHP001.do?menuCd=FN01010101 [retrieved on 11 October 2014]

KIII – Knowledge Industry Information Institute [지식산업정보원] (2014) 대체에너지 풍력/태양광산업 실태분석 및 ESS 기술개발/발전전망 (The analysis of alternative wind and solar industry and ESS technology development prospect. KIII. Seoul.

KIM Hoon-nam (2013) KEMCO and the government must compensate for '9·15 Black out'. Money today news. http://www.mt.co.kr/view/mtview.php?type=1&no=2013122914433540526&outlink=1 [retrieved on 30 June 2014]

KIM Jincheol (2013) 신재생에너지 보급률 국제사회서 '낙제' (The failure of new and renewable energy distribution rate in international society. Energy times). http://www.energytimes.kr/news/articleView.html?idxno=19786 [retrieved on 02 October 2014]

KIM Jungyoo (2014) Sunshine for solar energy industry. Etoday. http://www.etoday.co.kr/news/section/newsview.php?idxno=862310 [retrieved on 18 August 2014]

KIM Kwang-su, Lee Yu (2009) 한국공기업의 개혁 방향 (Reform direction of state owned-enterprises in South Korea). Industrial management research 22 (1) 1-25

KIM Youngkyung, CHANG Byungman (2012) Estimation of LCOE for Korean PV Projects: For the Ones that Financial Investors Participated in. New & Renewable Energy 2012.9 Vol. 8, No.3

KIM Young-jik (2014) The Contemporary Korean Politics and System Theoretical Analysis: Theories and Applications. Korean Association for Political and Diplomatic History. Vol.34 no.1 p.113-146

KIMR – Korea Industrial Marketing Research [한국산업마케팅연구소] (2013) 2013 신재생에너지 분야별 시장동향과 기술개발 현황 (New and renewable energy market trend and technology development situation). KIMR, Seoul.

KMA - Korea Meteorological Administration [기상청] (2008) 태양에너지 최적 활용을 위한 기상자원 분석 보고서 (Report of meteorological resource analysis for optimal solar energy using). KMA, Seoul.

KNREA – Korea New and Renewable Energy Association (2014) Introduce- about us. http://www.knrea.or.kr/ENG/main.asp [retrieved on 28 June 2014]

KNREC – Korea New and Renewable Energy Center (2014) the promotion of renewable uses for residential house. http://www.knrec.or.kr/knrec/12/KNREC120100.asp

[retrieved on 26 June 2014]

KOFOED-WIUFF Anders, SANDHOLT Kaare, and MARCUS-MOLLER Catarina (2006) Renewable Energy Technology Deployment (RETD)-Barriers, Challenges, and Opportunities. Ea Energy Analyses.

KOPIA – Korea Photovoltaic Industry Association (2014) Who we are – about us. http://kopia.asia/en/subpage.php?p=m11&tableindex=1 [retrieved on 28 June 2014]

Korea National Statistical Office 통계청 (2013) Korea Statistical Yearbook 2012 (2012 한국통계연감). Statistics Korea. Daejeon.

KOST Christoph, MAYER Johannes N, HARTMAN Niklas, SENKPIEL Charlotte, PHILIPPS Simon, NOLD Sebastian, LUDE Simon, SAAD Noha, SCHLEGL Thomas (2013) Levelized Cost of Electricity Renewable Energy Technologies. Fraunhofer Institute for Solar Energy Systems ISE. Freiburg.

KOWALSKI Przemyslaw, BÜGE Max, SZTAJEROWSKA Monika, EGELAND Matias (2013) State-Owned Enterprises: Trade Effects and Policy Implications. OECD Trade-Policy Papers, No. 147, OECD Publishing

KPMG (2014) Taxes and incentives for renewable energy. Japan. http://www.kpmg.com/global/en/issuesandinsights/articlespublications/taxes-and-incentives-for-renewable-energy/pages/japan.aspx [retrieved on 13 October 2014]

KPX – Korea Power Exchange (2014) Electricity market statistics 2013. KPX.

KREWITT Wolfram, SIMON Sonja, and PREGGER Thomas (2008) Renewable energy deployment potentials in large economies. Stuttgart, DLR (German Aerospace Center)

KREYCIK Claire, VIMMERSTEDT Laura, DORIS Elizabeth (2010) A Framework for State-Level Renewable Energy Market Potential Studies. Colorado, NREL (National Renewable Energy Laboratory) http://www.nrel.gov/docs/fy10osti/46264.pdf [retrieved on 09 January 2013]

KUDO Rei, UCHIYAMA Akihiro, YAMAZAKI Akihiro, SAKAMI Tomonori, KOBAYASHI Eriko (2010) From solar radiation measurements to optical properties: 1998-2008 trends in Japan. Geophysical research letters, vol.37.

KWON Jun Beom (2014) The budget for new and renewable energy decreased again. Energy newspaper. http://www.energy-news.co.kr/news/articleView.html?idxno=23088 [retrieved on 14 July 2014]

KYOCERA (2010) Consolidated Financial Results of Kyocera Corporation and its Subsidiaries for the Year Ended March 31, 2010. Kyocera.

KYOCERA (2013) KYOCERA starts operation of 70 MW solar power plant, the largest in Japan. KYOCERA Corporation, Japan. http://global.kyocera.com/news/2013/1101_nnms.html [retrieved on 02 July 2014]

KYOCERA (2014) Consolidated Financial Results of Kyocera Corporation and its Subsidiaries for the Year Ended March 31, 2014. Kyocera.

KYOCERA Europe (2014) Solar modules. http://www.kyocerasolar.eu/index/products/download/English.html

[retrieved on 23 July 2014]

LAM Joseph C., WAN Kevin K.W., YANG Liu (2008) Solar radiation modelling using ANNs for different climates in China. Energy Conversion and Management. Vol: 49 p-1080-1090

LARSSON Simon, FANTAZZINI Dean, DAVIDSSON Simon, KULLANDER Sven, HÖÖK Mikael (2013) Reviewing electricity production cost assessment. Renewable and Sustainable Energy Reviews 30 (2013) 170-183.

LBNL - Lawrence Berkeley National Laboratory (2012) Key China Energy Statistics 2012. LBNL China Energy Group.

LEE Jonghyun (2014) 2 years delay in new and renewable energy RPS target. Chosun Biz. http://biz.chosun.com/site/data/html_dir/2014/06/09/2014060901230.html [retrieved on 28 June 2014]

LEE Sanghoon (2014) 한국에서 재생에너지 확대를 위한 정책적 과제 (Policy challenges for promoting renewable energy in Korea). Environment law and policy vol: 12, Kangwon University.

LI Huashan, Ma Weibin, LIAN Yongwang, WANG Xianlong (2010) Estimating daily global solar radiation by day of year in China. Applied Energy 87 (2010) 3011-3017.

LI Huashan, BU Xianbiao, LIAN Yongwang, ZHAO Liang, MA Weibin (2012) Further investigation of empirically derived models with multiple predictors in estimating monthly average daily diffuse solar radiation over China. The journal of Renewable Energy. Vol: 44 p.469-476.

LIN Jones (2014) China's National Solar Subsidy Programs. China Policy in Focus. https://sites.google.com/site/chinapolicyinfocus/china-s-solar-subsidy-programs/china-s-solar-industry/china-s-national-solar-subsidy-programs
[retrieved on 11 October 2014]

LO Kevin (2013) A critical review of China's rapidly developing renewable energy and energy efficiency policies. Renewable and Sustainable Energy Reviews 29 508-516.

LO Kevin (2014) Energy-Related Carbon Emissions of China's Model Environmental Cities. Geography Journal. Volume 2014, Article ID 204745

LOBO Rita (2012) Keiretsu for a new age. World Finance. http://www.worldfinance.com/strategy/keiretsu-for-a-new-age
[retrieved on 04 July 2014]

LOPEZ Anthony, ROBERTS Billy, HEIMILLER Donna, BLAIR Nate, PORRO Gian (2012) U.S Renewable Energy Technical Potentials: A GIS-Based Analysis. Denver. NREL

MAKRIDES George, ZINSSER Bastian, GEORGHIOU George E, SHUBERT Markus, WERNER Jügen H. (2010) Potential of photovoltaic systems in countries with high solar irradiation. Renewable and Sustainable Energy Reviews Vol: 14 Issue: 2 p.754-62

MATSUO Yuhji, YAMAGUCHI Yuhji (2013) The Rise in Cost of Power Generation in Japan after the Fukushima Daiichi Accident and Its Impact on the Finances of the Electric Power Utilities. The Institute of Energy Economics. Novermber 2013.

MATUSZKO Dorata (2013) Long-term variability in solar radiation in Krakow based on measurements of sunshine duration. International journal of climatology, 34: 228-234.

McKinsey Quarterly (2014) The disruptive potential of solar power. http://www.mckinsey.com/insights/energy_resources_materials/the_disruptive_potential_of_solar_power [retrieved on 18th July, 2014]

McLELLAN Benjamin C., ZAHNG Qi, UTAMA N. Agya, FARZANEH Hooman, ISHIHARA Keiichi N. (2013) Analysis of Japan's post-Fukushima energy strategy. Energy Strategy Reviews 2 (2013) 190-198.

METI - Ministry of Economy, Trade and Industry (2011) Feed-in Tariff Scheme for Renewable Energy. METI Agency for Natural Resources and Energy. Tokyo.

METI (2012) Feed-in Tariff scheme in Japan. METI Agency for Natural Resources and Energy. Tokyo.

MIC – Ministry of Internal Affairs and Communications (2013) Statistical handbook of Japan. Tokyo.

MING Zeng, XIMEI Liu, Na Li, SONG Xue (2013) Overall review of renewable energy tariff policy in China: Evolution, implementation, problems and countermeasures. Renewable and Sustainable Energy Reviews 25: 260-271.

Ministry of Land, Transport and Martime Affairs (2012) Cadastral Statistics Annual Report 2012. Ministry of Land, Transport and Martime Affairs. Gwacheon. 2012

MKE – Ministry of Knowledge Economy [지식경제부] (2010) 신재생에너지산업 발전전략 (New renewable energy industry development strategy). MKE.

MKE and KEEI-Korea Energy Economics Institute (2012) 에너지통계연보 (Yearbook of Energy Statistics) 2012. KEEI. Uiwang.

MOFCOM – Ministry of commerce People's Republic of China (2013) Renewable Energy Law of the People's Republic of China. http://english.mofcom.gov.cn/article/policyrelease/questions/201312/20131200432160.shtml [retrieved on 23 June 2014]

MOLEG – Ministry of Government Legislation (2011) Act on the promotion of the development, use, and diffusion of new and renewable energy. http://www.moleg.go.kr/english/korLawEng?pstSeq=57707

[retrieved on 17 April 2014]

MOTIE – Ministry of Trade, Industry and Energy 산업통상자원부 (2008) 제 1 차 국가에너지기본계획 (The first national energy master plan). MOTIE.

MOTIE (2014a) Act on the promotion of the development, use and diffusion of new and renewable energy. MOTIE. Sejong.

MOTIE (2014b) 제 2 차 국가에너지기본계획 (The second national energy master plan). MOTIE. Sejong.

MORADI Isaac (2009) Quality control of global solar radiation using sunshine duration hours. The journal of Energy Vol: 34, Issue 1, p.1-6.

MUHAMMAD-SUKKI Firdaus, ABU-BAKAR Siti Hawa, MUNIR Abu Bakar, YASIN Siti Hajar Mohd, RAMIREZ-INIGUEZ Roberto, McMEEKIN Scott G., STEWART Brian G., SARMARH Nabin, MALLCIK Tapas Kumar, RAHIM Ruzairi Abdul, KARIM Md Ershadul, AHMAD Salman, TAHAR Razman Mat (2014) Feed-in tariff for solar photovoltaic: The rise of Japan. Renewable Energy 68 (2014) 636-643.

MYOJO S., OHASHI H (2012) Effects of consumer subsidies for renewable energy on industry growth and welfare: Japanese solar energy. In: 39th Annual conference of European association for research in industrial economics, Rome; 2012. pp. 1-24.

NA Sang-il, BAEK Shin-cheol, PARK Jin-ki, PARK Jong-hwa (2012) Daily global solar radiation estimate in the South Korea based on geostationary satellite remote sensing. Cheongju, Chungbuk National University.

NAHN Nguyen Thanh, HA-DUONG Minh (2008) Economic Potential of Renewable Energy in Vietnam's Power Sector. Energy Policy 37 (2009) 1601-1613.

NAKAMURA Yugo (2013) Cost of renewable energy. Revision 2013- Creating a new renewable energy future. Bloomberg. Tokyo.

NAM Sido, OH Heegab [남시도, 오희갑] (2006) 태양광 발전에 관한 기술동향분석 (The analysis of solar energy technology trend). Ministry of Science & Technology, Korea Institute of Science and Technology Information.

NASA - National Aeronautics and Space Administration (2008) Surface meteorology and Solar Energy' https://eosweb.larc.nasa.gov/sse/global/text/global_radiation [retrieved on 06 March 2014]

NBSC - National Bureau of Statistics of China (2009) China Statistics 2009. Beijing. China Statistics Press

NBSC (2010) China Statistics 2010. Beijing. China Statistics Press.

NBSC (2011) China Statistics 2011. Beijing. China Statistics Press.

NBSC (2012) China Statistics 2012. Beijing. China Statistics Press.

NBSC (2013) China Statistics 2013. Beijing. China Statistics Press.

NDRC – National Development and Reform Commission (2007) Medium and Long-Term Development Plan for Renewable Energy in China. People's Republic of China. http://www.martinot.info/China_RE_Plan_to_2020_Sep-2007.pdf

[retrieved on 23 June 2014]

NEDO – New Energy and Industrial Technology Development Organization (2013) NEDO 日射量データベース閲覧システム (Solar radiation database reading system) http://app7.infoc.nedo.go.jp/colormap/colormap.html [retrieved on 20 March 2014]

NIMR – National Institute of Meteorological Research (2014) Meteorological resources map data. Yearly direct irradiation. http://www.greenmap.go.kr/

[retrieved on 03 March 2014]

NOAA – National Oceanic and Atmospheric Administration (1998) Climate Normals 1961-1990 by WMO Regional Association.

ftp://ftp.atdd.noaa.gov/pub/GCOS/WMO-Normals/RA-II/ [retrieved on 26 April 2014]

NPC – the National People's Congress of the People's Republic of China (2005) Renewable Energy Law of the People's Republic of China.

http://www.npc.gov.cn/englishnpc/Law/2007-12/13/content_1384096.htm

[retrieved on 17 April 2014]

NREL – National Renewable Energy Laboratory (2012) Concentrating Solar Power Basics. http://www.nrel.gov/learning/re_csp.html [retrieved on 07 May 2014]

OCI (2013) OCI Annual Report 2012. OCI Company. Seoul. http://www.oci.co.kr/upfile/report/2013_Annual%20Report_Eng%28web%29.pdf [retrieved on 15 July 2014]

OCI (2014) OCI Annual Report 2013. OCI Company. Seoul. http://www.oci.co.kr/invest/ir_enterprise_view.asp?idx=3358&pageNo=1 [retrieved on 15 July 2014]

OH Si-Deok, LEE Yeji, YOO Yungpil, KIM Jinoh, KIM Suyong, SONG Seung Jin, KWAK Ho-Young (2012) A support strategy for the promotion of photovoltaic uses for residential houses in Korea. Energy Policy 53. P.248-256

OHIRA Tatsuya (2006) Measures to Promote Renewable Energy and the Technical Challenges Involved. Science & Technology Trends.

OLIVIER Jos G.J, JANSSENS-MAENHOUT Greet, MUNTEAN Marilena, PETERS Jeroen A.H.W. (2013) Trends in global CO2 emissions 2013 report. Hague. Netherlands Environmental Assessment Agency.

Open EI (2014) Solar Resources by Class per Country. http://en.openei.org/datasets/node/498 [retrieved on 06 March 2014]

OSBORNE Mark (2013) Polysilicon prices at Wacker fell 50% in 2012. http://www.pv-tech.org/news/polysilicon_prices_at_wacker_fell_50_in_2012 [retrieved on 09 October 2014]

OUYANG Xiaoling, LIN Boqiang (2014) Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. Energy Policy (2012) 64-73

PATTON Dominique (2012) China makes surprise cut to Golden Sun solar subsidies. Rechargenews. http://www.rechargenews.com/solar/article1299080.ece

[retrieved on 11 October 2014]

PV insight (2014) Home. http://pvinsights.com/index.php [retrieved on 20 August 2014]

QIAN Xuan, YAO yong-qiang, LI Jun-rong, Zhou Yun-he, WANG Shuai, LIU Li-young, YIN Jia (2012) Analysis of All-China Sunshine Conditions of Site Selection for Large Solar Telescopes. Chinese Astronomy and Astrophysics 36, p.445-456.

REN21 – Renewable Energy Policy Network for the 21st Century (2011) Renewables 2013 global status report. REN21 Secretariat. Paris.

REN21 (2013) Renewables 2013 global status report. REN21 Secretariat. Paris.

REN21 (2014) Renewables 2014 global status report. REN21 Secretariat. Paris.

RESCH Gustav, HELD Anne, FABER Thomas, PANZER Christian, TORO Felipe, HAAS Reinhard (2008) Potentials and prospects for renewable energies at global scale. Journal of Energy Policy. Vol.36, Issue 11. November 2008, P.4048-4056

SACHS Jeffrey (2014) The age of Sustainable Development. In his speech in IIASA/OeAW public lectures on 12 March 2014.

SAKOH Katsuro (1986) Privatizing state-owned enterprises: A Japanese case study. Asian Studies Center. Backgrounder. Washington D.C. No.51. September.

SASAC - State-owned Assets Supervision and Administration Commission of the State Council (2008) Central SOEs. http://www.sasac.gov.cn/n2963340/n2971121/n4956567/4956583.html [retrieved on 24 June 2014]

Sharp (2014) Investor Relations. Financial data. http://www.sharp-world.com/corporate/ir/financial/highlight/index.html [retrieved on 23 July 2014]

Sharp UK (2014) Solar Products. http://www.sharp.co.uk/cps/rde/xchg/gb/hs.xsl/-/html/solar-products.htm [retrieved on 23 July 2014]

SHINO Kiyoshi, IKKI Osamu (2003) National Survey Report of PV Power Applications in Japan 2002. IEA.

SHYU Chian-Woei (2010) Renewable Energy Policy in Remote Rural Areas of Western China: Implementation and Socio-economic Benefits. The University of Bonn. Bonn.

SO Byung-Wuk (2012) A Study on analysis photovoltaic business under Renewable Portfolio Standar (RPS). Chonbuk National University.

SOLANGI K.H., ISLAM M.R., SAIDUR R., RAHIM N.A., FAYAZ H. (2011) A review on global solar energy policy. Renewable and Sustainable Energy Reviews 15 (2011) 2149-2163.

SONG Yen Ling (2013) China gas prices deregulating the market. Platts. https://www.platts.com/IM.Platts.Content%5Caboutplatts%5Cmediacenter%5Cpdf%5Cinsight-oct13-chinalng.pdf [retrieved on 01 Oct 2014]

SolarGIS (2014) Direct Normal Irradiation South Korea.

http://solargis.info/doc/_pics/freemaps/1000px/dni/SolarGIS-Solar-map-DNI-South-Korea-en.png [retrieved on 24 April 2014]

Solar Qcells (2010) Qcells annual report 2010. http://qcells.corporate-reports.net/reports/q_cells/annual/2010/gb/English/0.html [retrieved on 30 July 2014]

STANGELAND Aage (2007) The Potential and Barriers for Renewable Energy. Oslo, the Bellona Foundation.

STRITIH Uros, OSTERMAN Eneja, EVLIYA Hunay, BUTALA Vincenc, PAKSOY Halime (2013) Exploiting solar energy potential through thermal energy storage in Slovenia and Turkey. Renewable and Sustainable Energy Reviews Vol:25 p.442-461

TANAKA Nubuo (2013) Big Bang in Japan's energy policy. Energy Strategy Review 1. (2013) 243-246.

TANG W.J, YANG K, Qin J, CHENG C.C.K, HE J (2011) Solar radiation trend across China in recent decades: a revisit with quality-controlled data. Atmospheric Chemistry and

Physics. Vol.11, No.1: 393-406

TANG WenJun, YANG Kung, QIN Jun, MIN Min (2012) Development of a 50-year daily surface solar radiation dataset over China. Science China Earth Sciences. Vol.56, No.9: 1555-1565

TAYLOR Margaret R. Beyond technology-push and demand-pull: Lessons from California's solar policy. Energy Economics. Vol30, Issue 6, November 2008, p.2829-2854

TESKE Sven, MASSON Gaetan. (2011) Solar generation 6. Solar Photovoltaic electricity empowering the world. EPIA – European Photovoltaic Industry Association and Greenpeace International. Brussels, Amsterdam.

the World Bank (2012) Implementation completion and results report. China renewable energy scale-up program. Report No: ICR 00002077. The World Bank. Washington DC.

TIMILSINA Govinda, KURDGELASHVILI Lado, NARBEL Patrick A. (2011) A Review of Solar Energy-Markets, Economics and Policies. The World Bank. Washington, DC.

TOMINAGA Yuki (2014) The Power of Public Opinion and Renewable Policy in Japan. Carleton College. http://people.carleton.edu/~amontero/Yuki%20Tominaga.pdf [retrieved on 04 July 2014]

TOYAMA Yoshihiro (1998) Privatization of public enterprises and its problems in Japan. International Journal of Social Economics. Vol. 25 Iss: 2/3/4, pp.388-398

Trina solar (2014a) Trina solar. Products. http://www.trinasolar.com/us/product/index.html [retrieved on 17 July 2014]

Trina solar (2014b) Quarterly & Annual Reports. http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-reportsother [retrieved on 24 July 2014]

UNDP – United Nations Development Programme (2000) World Energy Assessment. New York, NY.

VERBRUGGEN Aviel, FISCHEDICK Manfred, MOOMAW William, WEIR Tony, NADAI Alain, NILSSON Lars J., NYBOER John, SATHAYE Jayant (2009) Renewable energy costs, potentials, barriers: Conceptual issues. Energy Policy 38 (2010) 850-861.

VERBRUGGEN Avie, LAUBER Volkmar (2012) Assessing the performance of renewable electricity support instruments. Energy Policy 45 (2012) 635-644

WANG Ying, ZHANG Lei (2010) Relationship between global solar radiation and sunshine duration for Northwest China. International journal of the Physical Sciences Vo. 5(7) pp.1023-1033

WAKABAYASHI Minako, KATAYAMA Yoichi (2012) Green Rush Hits Japan. Orrick, Herrington & Sutcliffe LLP; 2012. pp.1-4

WATANABE Chisaki (2013) Japan's High-Cost Renewable Energy Curbs Subsidy Impact. Bloomberg. http://www.bloomberg.com/news/2013-06-24/japan-s-high-cost-renewable-energy-curbs-subsidy-impact.html [retrieved on 13t October 2014]

WebJapan (2013) Governmental Structure. http://web-japan.org/factsheet/en/pdf/e08_governmental.pdf [Retrieved on 13 October 2014]

WGA - Western Governors' Association (2006) Solar Task Force Report. WGA. Denver.

WHEELER David (2008) A Solar Future for the World Bank in Southern Africa? Center for global development. http://www.cgdev.org/blog/solar-future-world-bank-southern-africa [retrieved on 23 April 2014]

WMO World Meteorological Organization (1988) Technical Regulations. General Meteorological Standards and Recommended Practices. Vol.1 1988 edition Basic Documents No.2 ISBN 92-63-18049-0

XIA X.A, WANG P.C, CHEN H.B, LIANG F (2006) Analysis of downwelling surface solar radiation in China from National Centers for Environmental Prediction reanalysis, satellite estimates, and surface observations. Journal of geophysical research. Vol.111, D09103, doi: 10.1028/2005JD006405, 2006

XU Honghua, DOU Charlie, WANG Sicheng, LV Fang (2012) National Survey Report of PV Power Applications in China 2011. IEA cooperative programme on PVPS task 1 - exchange and dissemination of information on PV power systems; 2012.

XUN Yao Chen (2014) China's coking coal price low of $162.23 could affect urea stocks. http://finance.yahoo.com/news/china-coking-coal-price-low-130035056.html [retrieved on 18 August 2014]

YAMADA Hiroyuki, IKKI Osamu (2012) National Survey Report of PV Power Applications in Japan 2011. IEA cooperative programme on PVPS task 1 - exchange and dissemination of information on PV power systems; 2012.

YAMADA Hiroyuki, IKKI Osamu (2013) National Survey Report of PV Power Applications in Japan 2012. IEA cooperative programme on PVPS task 1 - exchange and dissemination of information on PV power systems; 2013.

YAMAMOTO Masamich, IKKI Osamu (2010) National survey report of PV Power Applications in Japan 2009. NEDO. Kawasaki. IEA PVPS.

YAMAMOTO Masamich, IKKI Osamu (2011) National survey report of PV Power Applications in Japan 2010. NEDO, IEA PVPS.

YANAGISAWA Akira, YOSHIOKA T., SUZUKI H., CHOI J.W., IKARII R., IWATA S., SHIBATA Y., ITO K. (2013) Economic and Energy Outlook of Japan for FY2014. Tokyo. The Institute of Energy Economics.

YANG Jichun, GU Zhipan, YANG Xuebin, ZHOU Xiangjiang (2012) Survey on Status and Developmental Strategy on Solar Energy Industry in JiaXing City, China. Advanced Materials Research Vols. 512-515 pp 285-288

Yingli (2011) Financial statements. Yingli. 2011. Baoding

Yingli (2014a) Yingli Solar. http://www.yinglisolar.com/en/ [retrieved on 17 July 2014]

Yingli (2014b) Financial statements. Yingli. 2014. Baoding

YU Xinag Lan 유향란 (2013) 중국재생가능에너지법 입법과정의 주요쟁점과 이해당사자 입장분석(Analysis on the Legislative Process in China: Renewable Energy Law Key Issues and Stakeholders Opinion). Seoul National University.

ZHANG Sufang, ANDREWS-SPEED Philip, ZHAO Xiaoli, HE Yongxiu (2013) Interactions between renewable energy policy and renewable energy industrial policy: A critical analysis of China's policy approach to renewable energies. Energy Policy 62 (2013) 342-353.

ZHANG Sufang, HE Yongxiu (2013) Analysis on the development and policy of solar PV power in China. Renewable and Sustainable Energy Reviews 21. 393-401.

ZHAO Ruirui, SHI Guang, CHEN Hongyu, REN Anfu, FINLOW David (2011) Present status and prospects of photovoltaic market in China. Energy Policy 39 (2011) 2204-2207

ZHENG Yongnian (2007) De facto federalism in China: reforms and dynamics of central-local relations. Hackensack: World Scientific; 2007.

List of figures

List of tables

Abbreviations

ANRE: Agency for Natural Resources and Energy

a-Si: Amorphous silicon

bbl: Barrel

BIPV: Building-Integrated grid-connected PV

BOS: Balance of System

CdTe: Cadmium-telluride

CIA: Central Intelligence Agency

CIGS: Copper-indium-gallium-(di)selenide

CIS: Copper-indium-(di)selenide

CREIA: Chinese Renewable Energy Industries Association

CRESP: China Renewable Energy Scale-up Program

CSP: Concentrating Solar Power

c-Si: Crystalline silicon

DART: Data Analysis, Retrieval and Transfer System

EBITDA: Earnings Before Interest, Tax, Depreciation and Amortization

EIA: U.S Energy Information Administration

EJ: Exajoules

EPIA: European Photovoltaic Industry Association

EPRC: Electricity Industry Policy Research Center

EPSIS: Electric Power Statistics Information System

FIT: Feed-in Tariffs

FTA: Free Trade Agreement

GCV: Gross Calorific Value

GEF: Global Environment Facility

GW: Gigawatt.

IEA: International Energy Agency

IGCC: Integrated gasification combined cycle

IRENA: International Renewable Energy Agency

ISEP: Institute for Sustainable Energy Policies

JCRE: Japan Council for Renewable Energy

JFS: Japan For Sustainability

JMA: Japan Meteorological Agency

JPEA: Japan Photovoltaic Energy Association

JREF: Japan Renewable Energy Foundation

J-PEC: Japan Photovoltaic Expansion Center

KEEI: Korea Energy Economics Institute

KEMCO: Korea Energy Management Corporation

KEPCO: Korea Electronic Power Corporation

KIII: Knowledge Industry Information Institute

KMA: Korea Meteorological Administration

KNREA: Korea New and Renewable Energy Association

KNREC: Korea New and Renewable Energy Center

KOPIA: Korea Photovoltaic Industry Association

kW: Kilowatt

kWh: Kilowatt hour

LBNL: Lawrence Berkeley National Library

LCOE: Levelized cost of electricity

LNG: Liquefied natural gas

mc-Si: Multi-crystalline silicon

MENA: Middle East and North Africa

METI: Ministry of Economy, Trade and Industry

MIC: Ministry of Internal Affairs and Communications

MKE: Ministry of Knowledge Economy

MOFCOM: Ministry of commerce People’s Republic of China

MOTIE: Ministry of Trade, Industry and Energy

MT: Meric ton

MW: Megawatt

MWh: Megawatt hour

NASA: National Aeronautics and Space Administration

NASDAQ: National Association of Securities Dealers Automated Quotations

NBSC: National Bureau of Statistics of China

NCEP: National Center for Environment Prediction

NDRC: National Development and Reform Commission

NEA: National Energy Administration

NEC: the National Energy Commission

NEDO: New Energy and Industrial Technology Development Organization

NGO: Non-Governmental Organization

NOAA: National Oceanic and Atmospheric Administration

NPC: National People's Congress

NREL: National Renewable Energy Laboratory

NYSE: New York Stock Exchange

OECD: Organization for Economic Co-operation and Development

O&M: Operation and Maintenance

POA: Plane of array

POSCO: Pohang Iron and Steel Company

PV: Photovoltaic

PWh: Petawatt per hour

RMB: Renminbi

RPS: Renewable Portfolio Standards

SASAC: State-owned Assets Supervision and Administration Commission of the State Council

SCE: Standard Coal Equivalent

SOE: State-Owned Enterprise

sc-Si: Single-crystalline silicon

TEPCO: Tokyo Electric Power Company Incorporated

TOE: Tonnage of oil equivalent

TWh: Tera Watt hour

UNDP: United Nations Development Programme

USD: United States Dollar

WCED: The United Nations World Commission on Environment and Development

WGA: Western Governors' Association

WMO: World Meteorological Organization

Wp: Watt peak

μc-Si: Micro-crystalline silicon

Abstract

The thesis analyzes the solar energy potential in China, South Korea, and Japan by using the framework developed by the National Renewable Energy Laboratory on the dimensions: Resource, Technology, Economy and Market. More specifically, the resource potential focuses on the solar radiation quantity and the time of availability (i.e. sunshine duration). The technical dimension covers the calculated technical potential by regional area. The economic potential shows the levelized costs of electricity (LCOE) of selected energy sources in comparison to solar PV. Finally, the analysis of the market potential includes a review of the market potential, the development of demand and supply as well as the trends of energy use, current prices and market players, and a viability analysis of the policy framework in all three countries.

The analysis is based on extensive literature analysis and quantitative data analysis of statistics provided by international organizations, national statistics, and scholarly articles. Data was collected through desk research as well as direct investigation at Chinese and South Korean national libraries, the Expo Solar PV Conference 2014 in South Korea and the International Conference on Concentrating Solar Power and Chemical Energy Systems in China (SolarPACES 2014).

Among the three countries, China shows the highest resource potential in terms of solar radiation. Among Chinese provinces, Tibet, Tsinghai, and Xinjiang have the most abundant solar resource. In South Korea, the two provinces Gyeongsangbuk and Gyeongsangnam indicate the highest solar radiation in relation to the rest of South Korea. In Japan, the south-western areas such as Osaka, Hiroshima, and Kumamoto receive higher solar radiation than the north-east.

The technical potential was calculated by referring to the potential roof top area in Chinese provinces and to the potential surface useable for PV-modules on building sites in South Korean and Japanese cities. Results show that the Chinese provinces Xinjiang, Tibet, and Inner Mongolia have a large technical potential with respect to the area size. Seoul, Busan, and Daegu were calculated to have the highest technical potential regarding useable building sites among South Korean cities. In Japan, Tokyo was assessed as having the highest technical potential in terms of building areas for dwellings in Japan.

Looking at the economic potential in three countries, solar energy still appears unattractive in terms of LCOE compared to conventional energies and to renewable energy sources, even if climate change cost are included into the calculation.

Lastly, the market potential shows that solar energy still constitutes for a minority with respect to total energy consumption and renewable electricity generation in all three countries. However, it is revealed that companies are already gaining much profit out of solar energy related products reflecting a growing market. There are also positive signs of fostering solar energy in China, South Korea, and Japan on policy level.

Zusammenfassung

Die vorliegende Arbeit analysiert das Solarenergiepotenzial in China, Südkorea und Japan, auf der Basis des vom National Renewable Energy Laboratory entwickelten Frameworks welches auf Ressourcen, Technik, Wirtschaft und Markt zielt. Das Ressourcenpotenzial ist die Menge an Sonnenstrahlung und Dauer der Verfügbarkeit (dh Sonnenscheindauer). Die technische Dimension umfasst das berechnete technische Potenzial einer Region. Das wirtschaftliche Potenzial erfasst die Kosten für Strom (LCOE) ausgewählter Energiequellen im Vergleich zu Photovoltaik. Anschließend umfasst die Analyse des Marktpotenzials eine Überprüfung des Marktpotenzials, Angebot und Nachfrage sowie die Trends der Energienutzung, aktuelle Preise und Marktteilnehmer und eine Analyse des politischen Rahmens in allen drei Ländern.

Curriculum Vitae

Personal information

Name	Seunghwan Jung
Email	hwan505@hotmail.com
Nationality	Republic of Korea

Education

Since 03.2012	University of Vienna M.A East Asian Economy and Society
03.2007-08.2010	Ajou University B.A Business Administration
09.2009-02.2010	FH-Salzburg Exchange student
03.2002-06.2006	Anyang University Tourism

Language skills

Korean	Native language
English	Fluent
German	Intermediate
Japanese	Basic
Chinese	Basic

Activities

09.2014	Presentation at SolarPACES 2014 conference in Beijing, China
10.2012-09.2014	Representative of Korean student association in Austria
06.2014, 09.2013, 06.2013	Research assistant and organizing member at RiSE conference in Vienna, Austria and Seoul, S.Korea
07.2013	Organizing member of AKSE conference in Vienna, Austria
04.2013-07.2013	Tutoring Korean at Vienna University
Since 08.2012	Interpreter as a freelancer (Korean and English)
05.2010-02.2012	Working at KCC Corporation as an International salesman (fulltime) in Seoul, S.Korea
01.2010-04.2010	Internship at Life Products Marketing GmbH in Vienna, Austria
07.2009	Representative of People's Republic of China at National Model UN conference in Gyeonggi, S.Korea

04.2009-07.2009	Internship at Millennium Hilton hotel in Seoul, S.Korea
11.2007-01.2008	Internshipt at ICmedia Direct in New York, USA
02.2004-02.2006 (06.2005-12.2005)	Military service in Chungcheong, S.Korea (Dispatched to Arbil, Iraq)
03.2003-06.2003	Departmental student representative at Anyang University

<u>Awards</u>

08.2009	Excellence award at 'National University Student Thesis Competition' by Dong-bu Insurance Company - *How global financial crisis in 2009 impacts on insurance industry in South Korea*
06.2009	The employee of the month by Millennium Seoul Hilton
12.2005	The Army Chief of Staff Citation by Republic of Korea Army