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Outlook of Power Generation Technology Cost in China

A Master Thesis Written in Collaboration with Statkraft AS

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Abbreviations

BNEF	Bloomberg New Energy Finance
BoP	Balance of Plant
CAPEX	Capital Expenditures
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CHP	Combined Heat Power
COD	Commercial Operational Date
CPV	Concentrating Photovoltaics
CSP	Concentrating Solar Power Plants
EIA	Energy Information Administration
EPC	Engineering, Procurement and Construction
IAEA	International Atomic Energy Agency
IDC	Interest During Construction
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
LCOE	Liberalized Cost of Energy
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-Operation and Development
OPEC	Organization of Petroleum Exporting Countries
OPEX	Operational Expense
O&M	Operation and Maintenance
PV	Photovoltaic
TOC	Total Overnight Cost
WACC	Weighted Average Cost of Capital
WEC	World Energy Council

Abstract

This project is part of the broader project (hereinafter "Broad Project") commissioned by the Technology Analysis unit in Innovation department of Statkraft AS to study the technology development path and Levelised Cost of Energy (LCOE) for both thermal and renewable power generations in emerging markets that Statkraft AS is present or has deep interest in, namely China, India, Brazil, Chile, Peru and Turkey. The project aims to project Total Overnight Cost (TOC) and LCOE of coal, natural gas, onshore wind and solar PV in these countries up to 2035, using Statkraft in-house excel model called "Cost Project Model". By comparing these costs across technologies and countries, Statkraft will be able to devise its medium-term investment strategy based on competitiveness of each technology and country.

China is of particular interest to Statkraft even though it does not have significant investment in the Chinese market yet. The rationale is that China is believed to be the price setting country for most power generation technologies, particularly coal, solar PV, wind and potential nuclear through 2035. Given that China is already the top country in terms of newly installed capacity every year for these technologies, and that China has developed its own technologies and supply chain capabilities, it is not surprising to conclude that other markets, especially the emerging markets under this project will have their costs converging to that of China in the long term.

Therefore this particular project focuses on two aspects: the Chinese supply chain and export potential of Chinese technologies, and costs of power generation technologies up to 2035 in China. The Broad Project limits the scope to coal, CCGT, solar PV and onshore wind in China, Brazil, Chile, Peru, India and Turkey. This project will also touch upon nuclear as it is a very important part of Chinese energy mix in the long term, and is currently being promoted by the Chinese government as one of the two pillars of Chinese machinery export.

Chinese technologies, domestic installed capacity, current and historical export, production capacity, future production expansion were studies both quantitatively and qualitatively. It is concluded that except CCGT, China will be the price setting country for TOC for solar PV, wind, and coal and nuclear through 2035. Therefore in the actually modelling of other countries, their assumptions were adjusted slightly so that they costs will converge to that of China through 2035.

Both technical and financial data including CAPEX, OPEX, capacity factor, availability, fuel efficiency, construction time, and owner costs were collected for projects that were recently commissioned or planned in China. Assumptions such as WACC, economic lifetime and fuel

prices were collected from renowned sources and adjusted to the judgement of the author and Statkraft on current and forecasted market conditions.

The results of the simulation confirms the hypothesis that coal will remain to be the cheapest sources of electricity in China through 2035 without taking into account any carbon pricing, additional pollution controls or curtailment. Wind is already a relatively cheap source of electricity that will be comparable to nuclear by 2020 and approaching the cost of coal by 2035. Solar PV will see the sharpest cost decline in the next two decades.

1 Introduction

1.1 Background

The landscape of energy industry across the global has undergone fundamental changes in the past decades, especially with the large scale introduction of renewable power to the generation of electricity to satisfy the ever-growing power demand as a result of tremendous economic development and urbanization in both developed and developing countries. Renewable power sources such as hydro and wind have been utilized by humans for many centuries. However, fossil fuel has always been the predominant source of energy, first biomass and then coal and gas since industrialization. People took it for granted the abundance of cheap fossil fuel thanks to our generous mother earth. It was not until the first oil crisis in 1973 due to Organization of Petroleum Exporting Countries (OPEC) oil embargo that many countries realized how dependent they were on fossil fuel, especially imported fossil fuel, and how scarce it would be as our appetite for energy kept on growing without any sign of slowing down.

The first oil crisis and subsequent crises, together with the “peak oil” theory, triggered major oil importing countries to rethink about their energy policy and for the first time, raised the goal of greater energy independence and security, notably the United States and Europe. To achieve energy independence, countries have to substitute imported fossil fuel with either domestically produced fossil fuel or other sources of energy. Hence renewable power technologies such as wind, solar, biomass, geothermal etc. became one of the options on the table and research in these technologies took off. For example, the Energy Independence and Security Act of 2007 in the United States has listed the increase of production clean renewables as one of its main objectives.

Of various renewable power generation technologies, hydro has long been exploited and is considered to be one of the cheapest sources of electricity generation. Today most of the available potential for hydropower has been exploited in developed countries and hydropower consists a considerable part of national power generation mix. According to International Energy Agency (IEA), 16.3% of the world's electricity (about 3500 TWh in 2010) is provided by hydropower. By comparison, as of 2012, nuclear power provides 12.8% of the world's electricity.

Other renewable technologies, however, were much more expensive to deploy than hydro and conventional fossil based generations. Simply to achieve energy independence may not be a sufficient reason for the large scale deployment of these more costly power generation technologies. But one major consequence of fossil fuel consumption has made it more than necessary to deploy them – global warming.

The burning of fossil fuel from coal and gas fired power plants, steel mills, cement plants etc has emitted a large amount of Greenhouse Gases (GHG) such as water vapor, carbon dioxide (CO_2), methane (CH_4), ozone (O_3), together with other hazardous pollutants in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC), in its 2014 report stated that scientists were more than 95% certain that most of global warming is caused by increasing concentrations of greenhouse gases and other human (anthropogenic) activities. Global warming leads to abnormal climate events such as extreme weather, drought, tsunami, rising of sea-level etc. Limiting the average global surface temperature increase of 2°C (3.6°F) over the pre-industrial average has been the target that was raised in many international conferences and climate negotiations.

To achieve that very ambitious target, we have to reduce our reliance on fossil fuel dramatically in the next decades or so. Kyoto Protocol, one of the most important international agreements linked to the United Nations Framework Convention on Climate Change (UNFCCC), ratified on 11 December 1997, set binding target for industrialized countries to limit their GHG emissions by 4.2% on average for the period 2008-2012 relative to the base year, which in most cases is 1990. Developing countries could also participate in the effort by investing in emission reduction projects and trade the resulting emission reduction credits with those under binding targets.

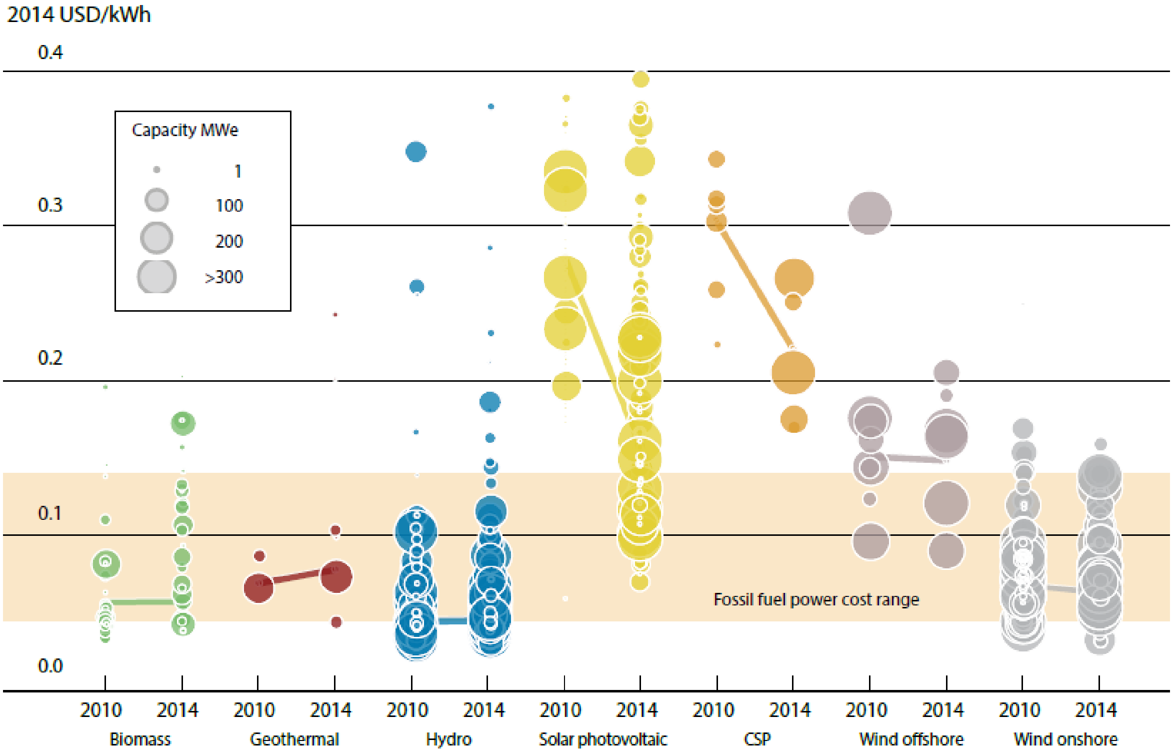
Since the ratification of Kyoto Protocol, various carbon trading/tax mechanisms have been implemented in most major countries and regions, including European Union Emission Trading System, Californian Cap and Trade System, Chinese domestic carbon trading pilot schemes etc. These carbon trading/tax system essentially put a price on carbon emissions, thereby increasing the cost of generating power from conventional fossil fuel based power plants.

Since then, renewables have gained more traction because of its “cleanness” and renewable nature which pose potential solution to the reliance of large scale urbanization on fossil fuel, particular in fast-growing developing countries. That, coupled with the oil price hike during the recent financial crisis, has paved way for the vast deployment of renewable energy into our society.

Europe has been the pioneer in both technology and investment in renewable power, especially countries like Germany, Spain and Italy which set very generous subsidy support for renewables such as wind and solar PV. These countries are also among the first and most important countries that invested heavily in the research and development of technologies and equipment associated with these renewable power generations. However, other countries, especially developing countries such China and India are catching up very fast after the financial crisis in 2009. By 2014, with 96GW of wind and 27GW of solar, China has been the top country in terms of both installed capacity per year and cumulative installed capacity in these two technologies. Besides, China now supplies about 50% of the world's solar PV panels, even after import restrictions from its major trade partners EU and US.

As a result of the vast deployment of renewable power around the world, costs of these technologies have come down substantially, though for some technology it drops more than for others. Prices have fallen dramatically in the past few years: solar PV falling by 80 per cent in six years, and on-shore wind by 40 per cent. The National Bank of Abu Dhabi (NBAD), in its presentation "Financing the Future of Energy Report" at the Global Financial Markets Forum, claimed that solar will be at grid parity within two years in 80% of the world (National Bank of Abu Dhabi , 2015).

Figure 1 LCOE from utility-scale renewable technologies, 2010 and 2014

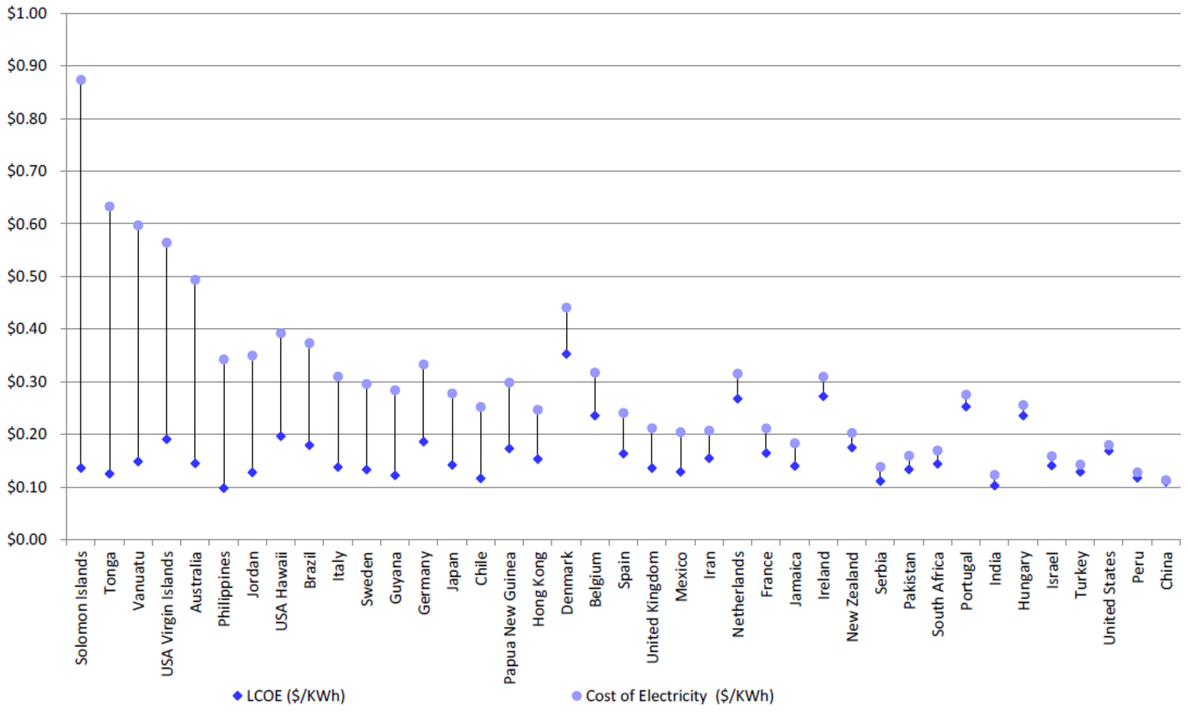


Source: (IRENA, 2015)

Technology cost not only changes due to time, it also varies a lot across countries. For instance, Deutsche Bank in its 2015 solar outlook calculated the LCOE of solar PV and cost of electricity for major countries and found out that they vary substantially across countries, with the Demark having the highest LCOE and India and Philippines having one of the lowest LCOE for solar PV projects. Statkraft also observed similar pattern. It estimated that Combined Cycle Gas

Turbine (CCGT) plants in Western Europe cost[1] 1.31 M$/MW while those in India cost 0.662 M$/MW. It concluded that supply chain was the main cause of such difference. The biggest cost component for a CCGT plant are the turbines, and the Indian plants built the turbines domestically under license GE reducing cost.

Figure 2 Solar PV costs in different countries



Source: (Deutsche Bank, 2015)

Technology costs also change due to changes in government policies and market conditions. For instance if government has a long term strategy for certain technology and invest heavily by setting favorable policies and subsidy schemes, as China did with solar PV, costs could come down dramatically within relatively a very short time frame. We are observing the same pattern that is happening with wind technology in China.

It should also be noted that different organizations usually come out with sometimes very different numbers for power generation technology costs. To make matters even worse, there are various ways to quantify the cost of electricity, depending on the purpose of comparison, timespan, location and industry that are making the comparisons. For instance, project developers might be more concerned with the total Capital Expenditures (CAPEX) than the LCOE as it comes to the development of a particular project. In contrast, bankers and institutional investors will be using project Internal Rate of Return (IRR) or equity IRR as

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[1] OCC and Owner's cost excluding IDC, all numbers in 2014 USD

measure of relative cost of the project. As for operators of the project, they will be looking mainly at the Operations and Maintenance (O&M) costs.

1.2 Research Motivation

In view of the above complications to accurately quantify the costs of electricity for different technologies and different countries, Statkraft AS, the largest producer of renewable energy in Europe developed its cost projection model to project LCOE based on learning rates and convergence effects of different technologies and countries.

Statkraft is Norway's largest and the Nordic region's third largest power producer. Its Core business areas within hydropower, wind power, gas power and district heating. It has 403 power and district heating plants with a total installed capacity more than 18 000 MW, and 29 district heating plants with an installed capacity more than 700 MW. 71.5% of the installed capacity is in Norway, then Europe outside the Nordics with 16.3%, the Nordics excluding Norway with 8.3% and the rest of the world with 3.9%.

Statkraft is interested in emerging markets including India, Brazil, Chile, Peru and Turkey. It does not have significant present in China yet. In order to better position itself in these markets and to devise long term investment strategy, it is necessary to do a thorough assessment of costs of different generation technologies over time in these markets. However, in order to do that, it has to include China in the analysis because China will be the price setting country for some of the power generation technologies, notably solar PV and coal at the moment and possibly wind in future.

Therefore Technology Analysis unit in Innovation department of Statkraft AS called for master students from each of the above countries to study the future technologies in his or her respective country.

1.3 Research Objective

The objective of this research is to twofold: qualitative study on supply chain and export potential of power generation technologies in China; quantitative study to calculate the economic lifetime cost of electricity in China by 2035.

The technologies in focus in the Broad Project that covers all mentioned countries include coal, CCGT, solar PV and wind. This particular study will also include nuclear as it will be presented in later chapters that nuclear will play an important part of Chinese energy mix up to 2035 and beyond. To the author’s knowledge, there has not been much research done on the forecast of LCOE of different generation technologies in China. Therefore this research also tries to give a broader set of audience a first introduction into the Chinese power market by assisting them to understand the costs of generations in China and long term trend.

Before the research started, the author assumed or believed that coal will still be the price setting technology in China within 2035 timeframe, as coal is abundant and cheap in China, and China is developing advanced coal technologies to cut down costs as well as reduce emissions from coal generations.

The remainder of this paper is organized as follows:

Chapter 2 will give an introduction to the Chinese power market and relevant technologies/supply chain in China. It will focus on the long term plan of Chinese deployment of these power generation technologies as well as their export potential.

Chapter 3 will present a summary of current available literature on learning curves, convergence effect and Levelised Cost of Energy (LCOE).

Chapter 4 will present the methodology used in this study, aka the Cost Project Model. It will explain the principle and theories behind, assumptions in the model, formula used and its outputs.

Chapter 5 will introduce the inputs used in the model and present the results of the simulation.

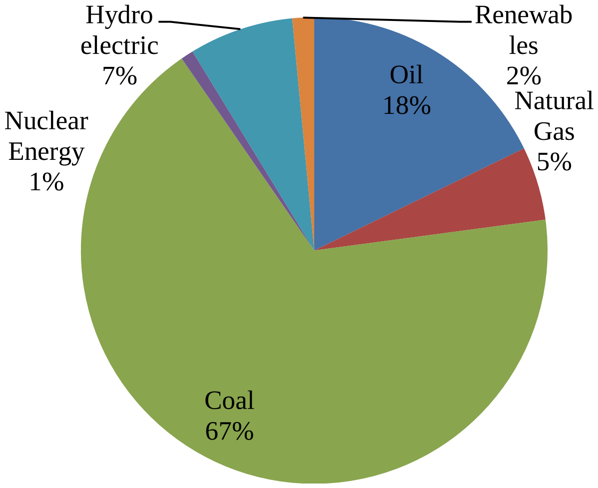
Chapter 6 will analyze the results presented in previous chapter.

Chapter 7 will summarize the research and conclude.

2 Chinese Supply Chain and Export Potential

With 67% of the total primary energy consumption in 2013, the Chinese energy paradigm is absolutely dominated by coal. Oil is the second most important source of energy that contributes another 18% of total primary energy consumption. The share of non-fossil fuel is only 10%, of which 7% is from hydro. The share of all renewables aggregated is only a marginal of 2% of total primary energy consumption in China.

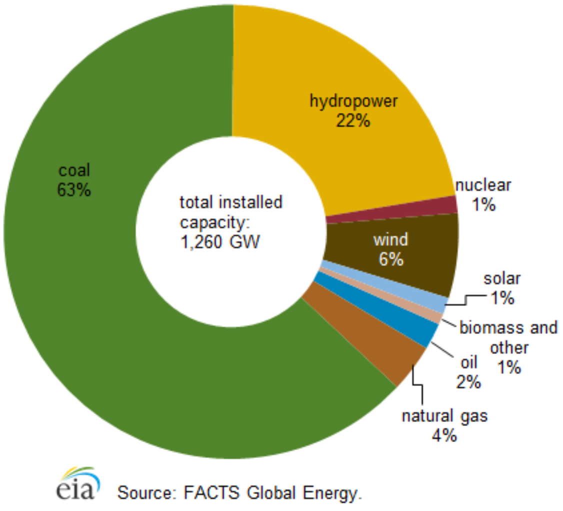
Figure 3 Total Primary Energy Consumption in China by Type, 2013



Source: BP Statistical Review 2014

In the electricity generation side, coal comprises another 63% of total installed capacity in China by the end of 2013. Hydropower contributes 22% of China's total installed capacity. Wind on the other hand, already reached 6% of total installed capacity, more than that of natural gas, nuclear, solar and biomass and others combined.

Figure 4 China's installed capacity share by fuel, end 2013



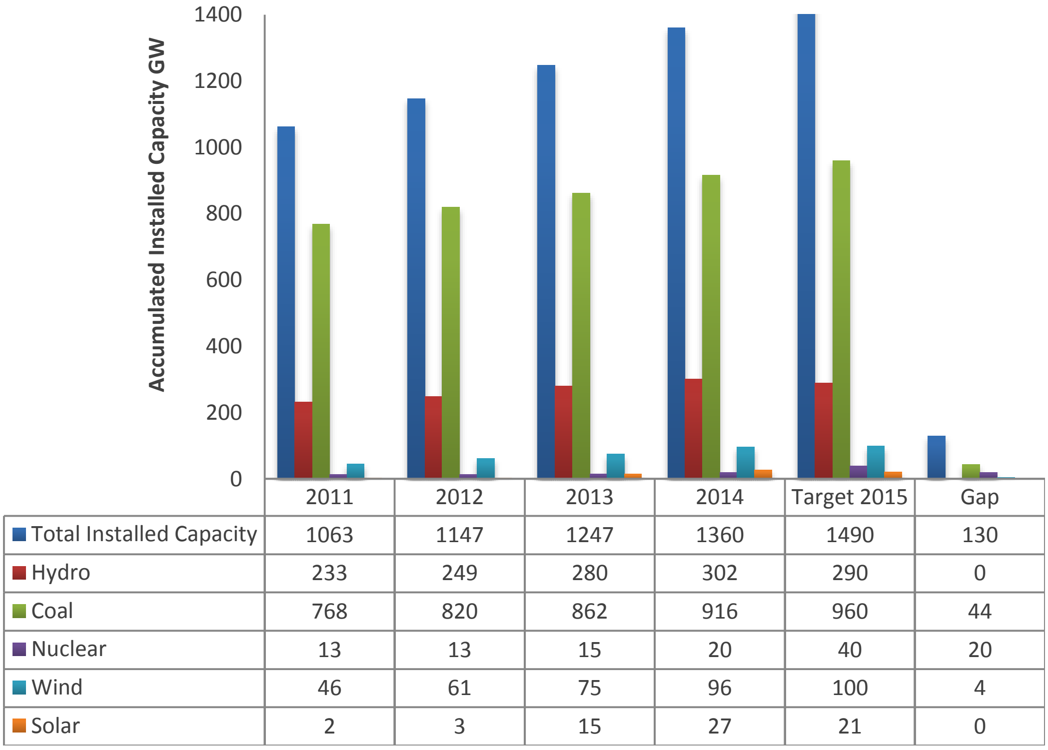
Source: EIA FACTS Global Energy

Due to fast growing economy, large scale urbanization and huge investment in infrastructure, Chinese power demand has been increasing rapidly over the last two decades. To satisfy such ever increasing power demand, China is exploiting all possible ways to generate power at the lowest cost. To be able to satisfy power demand has been the top priority for the energy sector for many years in the country. Therefore market leberilization has not seen any progress yet as the power sector in the country is still highly regulated and controlled by major giantic state-owned enterprises.

Over the last few years, China has increased its deployment of renewable power such as wind and solar in an unprecidented pace. In 2014, China installed 21GW of wind and 12GW of solar projects. By the end of 2014, China has installed capacity of 96GW of wind projects and 27GW of solar projects.

However, these numbers are still very small compared to the dominant type of power source which is coal. In 2014 China installed 54GW of coal fired power plants and by the end of 2014 it has total installed capacity of 916GW of coal fired power plants. Other energy sources such as gas, biomass etc still contribute a very marginal share of total installed capacity in Chinese power mix.

Figure 5 Installed capacity in China

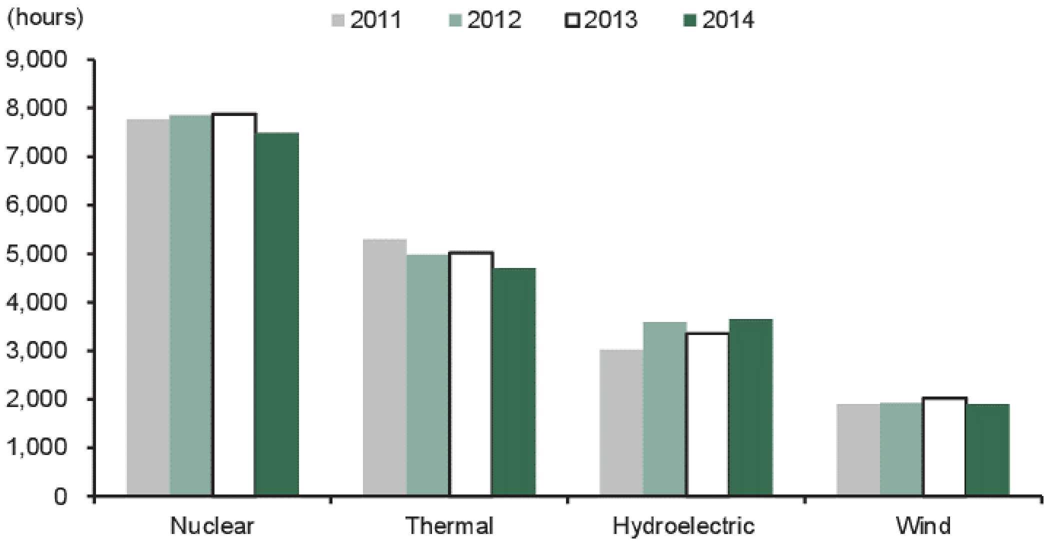


	2011	2012	2013	2014	Target 2015	Gap
🟦 Total Installed Capacity	1063	1147	1247	1360	1490	130
🟥 Hydro	233	249	280	302	290	0
🟩 Coal	768	820	862	916	960	44
🟪 Nuclear	13	13	15	20	40	20
🟦 Wind	46	61	75	96	100	4
🟧 Solar	2	3	15	27	21	0

Source: National Power Industry Data, China Electricity Council

However, things start to change as Chinese economy slows down lately. As the economy slows down, the increase in power demand begins to slow down as well. Moreover, as more renewable power penetrates to the grid at zero marginal cost, the Chinese power dispatch system is seeing some fundamental changes in the electricity production pattern. One of the most important consequences is the decreasing number of utilization hours for thermal power plants in China, as shown in the figure below. At times of low demand and high production from renewable power projects, thermal power plants are forced to shut down to give way to the lower cost of production.

Figure 6 Utilisation hour comparison for power generation in China



Source: China Electricity Council & BNP Paribas

China is not only deploying renewable power domestically, it has also developed full value chain in equipment manufacturing, engineering, construction, O&M etc in renewable technologies. In particular, China is now supplying most of the world’s solar PV panels. It also has ambitious plans to export its coal and nulear power generation technologies and equipment to the global market.

Given the rising importance of Chinese equipment and technology suppliers, investors and capital in the global energy production market, and the fact that Chinese domestic market is also experiencing some fundamental changes, it is therefore very crucial to understand the supply chain and export potential and strategy of Chinese power generation technologies in order to make a more comprehensive assessment of the cost of electricity and market development in other parts of the world.

2.1 Coal Fired Power Generation

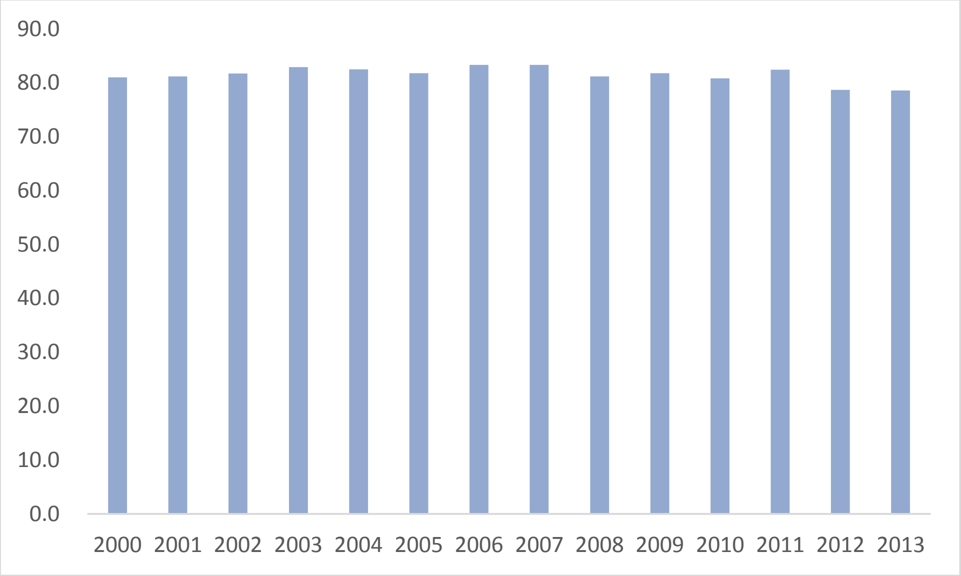
As mentioned earlier, coal is the major source of electricity in China. It is also the second largest source of greenhouse gas emissions in the country. China’s heavy reliance on coal is determined by its natural resource mix: China has abundant cheap coal in the country. China is the world’s largest coal producer, consumer and importer, and it accounts for half of the total coal consumption in the world (BP Statistical Review 2014).

The volume, quality, and geographical distribution of coal reserves throughout the country have important implications for China's energy policy. Most of the country's coal reserves lie in the north, while the majority of load centers lie in the south and east. Such uneven regional distribution of supply and demand leads to the fact that coal has to be transported long distances before it can reach the end user, an average of 400 kilometers (Sun, 2010).

Traditionally, coal price not regulated while electricity price regulated in China. Recent reform focuses on the linkage of coal-electricity prices. Transporting electricity is more economical than transporting coal. West-East electricity transmission project.

In September 2014 the State Council approved a national climate change plan including carbon emission intensity target of 40-45% reduction from 2005 to 2020, with good progress of almost 29% by the end of 2013. It aims to increase the shares of non-fossil fuels in primary energy consumption to about 15% by 2020 – at the end of 2013 it was 9.8%.

Figure 7 Coal as percentage of total electricity generated



Source: China Electricity Council

China started coal technology by importing technologies from developed countries. Each of the three major suppliers in China imported technology from three different global suppliers: Harbin from Toshiba, Shanghai Electric from Siemens and Dongfang Electric from Hitachi. Based on these imported technologies, China developed its own advanced coal technology with intellectual property and much lower cost.

To promote the research and design in advanced coal technology in China, the Chinese government initiated the National 700℃ USC Coal-Fired Power Generation Technology

Innovation Consortium which is a consortium consists of universities, domestic turbine and boiler suppliers, utilities and other research institutions. China is planning to build a first 700℃ advanced ultra-supercritical coal fired power plant which will be the most efficient coal fired power plant in the world.

China is also research and deploying Integrated Gasification Combine Cycle (IGCC) Technologies. China could be a leader in exporting IGCC technology with carbon capture worldwide over the next decade by building upon its extensive gasification experience and ability to manufacture technology quickly at competitive prices (Sung, 2014).

Table 1 1000MW Ultra Super-Critical Coal Turbine Technology in China

	Harbin Turbine	**Shanghai Electric**	**Dongfang Electric**
Source of Technology	TOSHIBA	SIEMENS	HITACHI
Configuration	25MPa/600℃/600℃	26.25MPa/600℃/600℃	25MPa/600℃/600℃

Source: China Electricity Council

Table 2 1000MW Ultra Super-Critical Coal Boiler Technology in China

	Herbin	Shanghai	Dongfang
Source	CE-MHI	ALSTOM(CE) ALSTOM(EVT)	BHK

Source: China Electricity Council

Coal is a major source of air pollution. China's power demand growth almost halved in 2014 to only 3.8%, the lowest level of growth over the past 10 years. While mild weather played a role, the fundamental reason was weak industrial output, with industry accounting for around three quarters of China's power demand.

Fundamentally, this option requires coal-fired power plants to deploy advanced pollutant mitigation technology and reduce emissions to levels similar to, or even lower than, gas-fired CCGTs. Compared with the special emissions limits on coal-fired power in Beijing/Tianjin/Hebei, Yangzi River Delta and Pearl River Delta, current CCGT emission requirements in China are 70% lower in PM, 30% lower in SO2 and 50% lower in NOx. However, China has nine recently commissioned ultra-low emission coal units that boast even higher environmental performance than CCGTs - around 90% lower in PM, and 85% lower in SO2 and NOx compared with the special limits to coal-fired power.

Therefore China has set the world’s most stringent emission standard for new coal fired power plants, the ultra-low emission standard. The new emission standard set upper limit for PM at

5mg/Nm3, SO2 at 35mg/Nm3 and NOx at 50mg/Nm3. The Shenhua Guohua Zhoushan coal fired power plant, commissioned on 25th June 2014, with installed capacity 300MW, is the first new coal fired power plant that implement technologies that makes it a very low emission coal fired power plant. The emissions could reach PM = 2.38mg/Nm3, SO2 = 0.68mg/Nm3, NOx = 30.29mg/Nm3 (Chen, 2014). It is estimated that most of the current coal fired power plants can be retrofitted to be able to comply with the ultra-low emission standard at a relatively low cost. Many provinces have set up plans and targets to implement such emission standard for all coal fired power plants within the next five years.

With low utilization rate domestically, excess building capacity and lower costs, Chinese coal technology has successfully ventured into the global market. In fact 49.3% of total contract value in 2014 came from the international market. Therefore we assume that China will still be the price setting country for coal fired power technology up to 2035.

2.2 Gas

Due to the dominance of coal fired power plants and cheap coal resources in China, gas has not been a big part of Chinese energy mix in the past decades. LNG prices in Asia is also the highest among all major hubs. Therefore to generate power from natural gas is way more expensive than from coal in China. As illustrated in figure 4, natural gas only contributes 4% of Chinese total installed capacity, and this number is expected to remain stable or slightly increase up to 2035.

Chinese gas fired power technology still relies on foreign majors. There are three major suppliers of gas turbines in China: Dongfang Electric, Harbin Electric and Shanghai Electric. The three major suppliers form joint venture with international firms such as Siemens and Alstom.

Right now most of the planned and new gas fired power plants are being deployed in the east part of China to replace coal fired power plants to reduce air pollution which is an increasingly important threat to the sustainable development of gigantic cities along the east coast. One of the biggest cause of air pollution in China is the burning of coal for heating purpose in the winter. Therefore most of these plants are combined heat and gas plants that produce more heat in winter for central heating purpose.

Gas fired power plants will not be deployed in China in the coming decades for several reasons. First of all, Asia traditionally has the highest LNG prices due to high demand and dependence on natural gas from Japan and Korea. Even with imported gas through pipeline from Middle East and Russia, it will still be more expensive than domestic coal. Secondly, Chinese advanced coal fired power plants are implementing more stringent emission standards that are comparable to gas fired plants. Therefore there is no major incentive to replace coal fired power plants with gas fired plants in a large scale. Last but not least, renewables are increasing getting competitive compared to gas fired technology. Given the large capital costs and long lifetime of a gas plant, it will not make sense to invest in a technology that will soon be less cost competitive than renewables.

Though gas technology will not be a big part of Chinese future power mix, there is still some initiatives going on to increase self-sufficiency of gas turbines and boilers in China. In September 2014, the three major domestic suppliers teamed up with universities and utilities to promote the research and development of Chinese own gas turbine technology. In October 20145, the first 50MW gas turbine experiment started at Dongfang Electric.

2.3 Wind

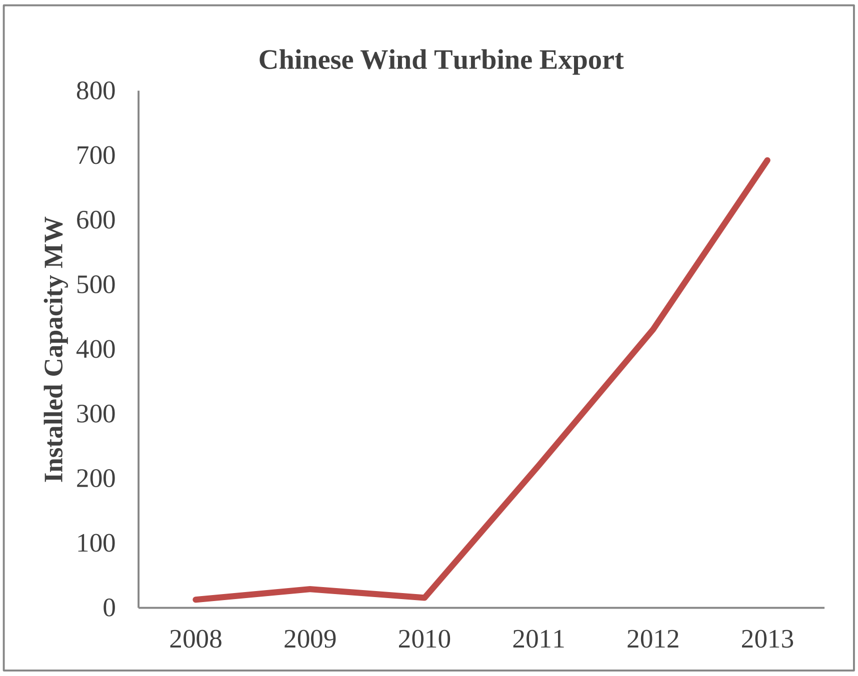
In 2010 China installed 17GW of wind. That quickly increased to 21GW in 2014. However, compared to the manufacturing capacity of wind turbines, Chinese new installed capacity is still growing at a relatively slower pace. China had a manufacturing capacity of 25GW of wind turbines in 2010, and by 2014 that number has risen to a staggering number of 40GW. The Chinese wind market stated out with foreign turbine suppliers and investor in the early 1990s. However, Chinese wind industry has developed into a relatively closed market over time. The aggregate market share of foreign turbine suppliers (namely Vestas, GE and Gamesa) decreased year by year from 7.5% in 2012 to 5.9% in 2013 and finally less than 1.8% in 2014 despite the fact that the overall installed capacity has been increasing very rapidly during the same period.

Therefore unlike solar PV panel manufacturing industry, China has accumulated almost 20GW of excess capacity in wind turbine manufacturing, equivalent to the total new installed capacity of wind in China in 2014. These excess capacity has not been exported successfully as it has been done in the solar industry. There are several reason for that. The major problem with Chinese wind turbines is that they are not as reliable as leading brands in the international market. Many wind turbine manufacturing firms started by importing technologies or set up joint ventures with international firms. During the last few years as wind is growing fast in China, the competition has been more focused on prices rather than quality and reliability.

As the market matures and excess capacity piles, the industry has gone through some consolidations. Leading firms are increasingly investing more in R&D to improve the quality and output of domestic wind turbines. Currently wind turbines of 2-5 MW are the mainstream in the Chinese market, but larger turbines are already been tested and some very large offshore wind turbines have been deployed in the Chinese offshore wind demonstration project for over two years.

Even though excess capacity for wind turbine is staggering, China did make some progress in exporting its wind turbines. In 2013 China exported around 700MW of wind turbines, most of it comes from top three manufacturers Goldwind, Sinovel and SANY (Annual Meeting of Major Wind Equipment Manufacturers 2014). Top destinations include USA, Australia, Ethiopia and Italy. The absolute number is still relatively low. However, the growth rate is quite high as shown in the figure below. The Chinese wind turbine export is growing exponentially in the past few year. As quality and output of Chinese wind turbines is improving, it is very likely that China will export more and more wind turbines just as it is doing now in the solar sector. Maybe not for offshore wind turbine but given the large excess capacity, exporting is one of the best way to utilize and achieve economy of scale to cut down costs. Therefore in this study we also assume that China will be the price setting country in onshore wind in the decades to come.

Figure 8 Chinese wind turbine export



Source: China Electricity Council

2.4 Solar

China installed 500MW of solar in 2010. It produced 10GW of solar panels in the same year. In 2014, there was 11GW of solar projects installed in China, and China has a production capacity of 33GW of solar panels, which is equivalent to 90% of world’s annual installed capacity.

Since the global financial crisis in 2008, the solar PV sector has gone through several fundamental changes. First of all, margin for panels went down dramatically due to overcapacity, fierce competition and export restriction to major market, EU. The once world’s largest solar PV panel maker Suntech filed for bankruptcy.

Following the collapse of solar PV panel prices and possible large scale bankruptcy of panel marker, the Chinese government came rescuing by making incentives through stimulus package to deploy solar PV projects domestically. The large scale domestic deployment of solar PV not only contribute to greener power supply to meet ever growing electricity demand, it also absorbed domestic overcapacity.

Several years after the financial crisis, China is still supplying most of the solve PV panels globally. However, the market is currently seeing some fundamental changes. Large solar panel makers are increasingly going downstream to invest in solar PV projects so that they can also deploy their panels. With cheap financing, they are also going into the global market and invest in not only emerging market but also matured market such as the UK. Some of them are also considering or are already preparing to set up YieldCo which is a vehicle to raise capital at very low cost. They are gradually transitioning from pure solar panel makers into Independent Power Producers (IPP), just like their American counterpart SunEdison is doing.

China EPC firms, with their accumulated engineering and construction experience in the domestic market, is also venturing into the global market to compete with international players. These EPC firms are backed by Chinese Ex-Im banks so that they not only offer best EPC prices but can also provide bridge finance, development costs etc so that their offer is better than their international competitors.

The synergy created by this approach will further reduce the cost of solar PV projects globally and this will have huge impact on cost of solar PV in the coming decade.

2.5 Nuclear

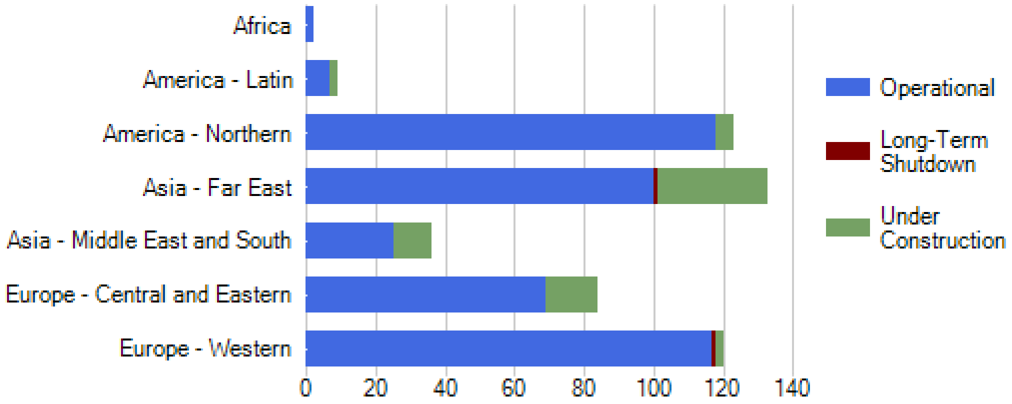
Nuclear power is very commonly deployed in most countries of the world because of its cost competitiveness even compared to thermal plants. Nuclear power plant is characterised by its very high capital costs and almost zero operating cost. Fuel cost is also a very minor part of the total cost of electricity generated from nuclear power plants. Therefore they are perfect to serve as baseload power.

Costs for a nuclear power plant can be broken down into three main components: capital costs, operating costs and external costs (World Nuclear Association, 2015). Capital costs include both overnight construction costs and financing costs. Operating costs include O&M, fuel costs, fund for plant decommissioning etc. The external costs, according to the World Nuclear Association, are defined as those actually incurred in relation to health and the environment, and which are quantifiable but not built into the cost of the electricity. It is the potential cost to the society but not included in the costs of the power plant and therefore not included in this study neither.

Though cost of electricity from nuclear power could be comparable to thermal power plants, nuclear power is also a controversial technology, especially after the Fukushima Daiichi nuclear accident in 2011. Many countries such as Japan and Germany are gradually phasing out nuclear power. However, the world is quite divided in the development of nuclear power. Many countries, especially countries in Asia are still building many new nuclear power plants and have very ambitious target to make nuclear a bigger role in their future energy mix, as presented in the figure below.

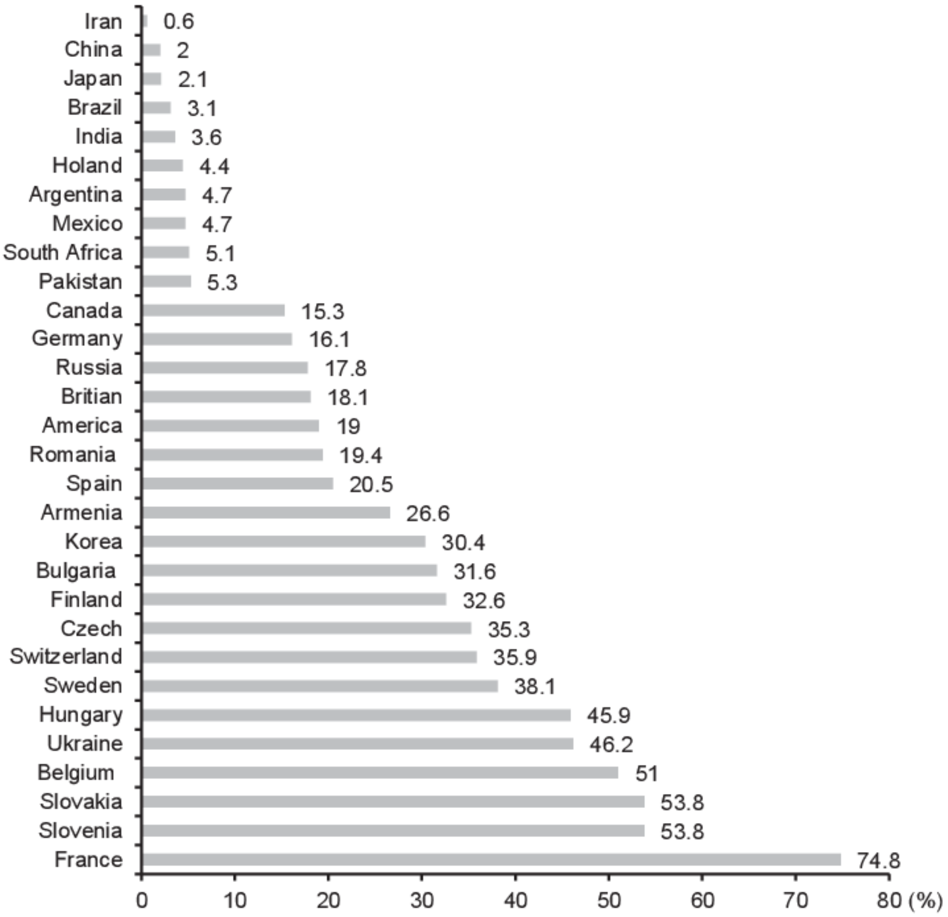
According to International Atomic Energy Agency (IAEA), By July 2014, there are 435 operational nuclear power reactors in 30 countries around the world and 72 are under construction in 15 countries (International Atomic Energy Agency, 2014).

Figure 9 Regional distribution of nuclear power plants



Source: IAEA Power Reactor Information System (PRIS)

Figure 10 Nuclear power generation as % of total power demand comparison in 2012



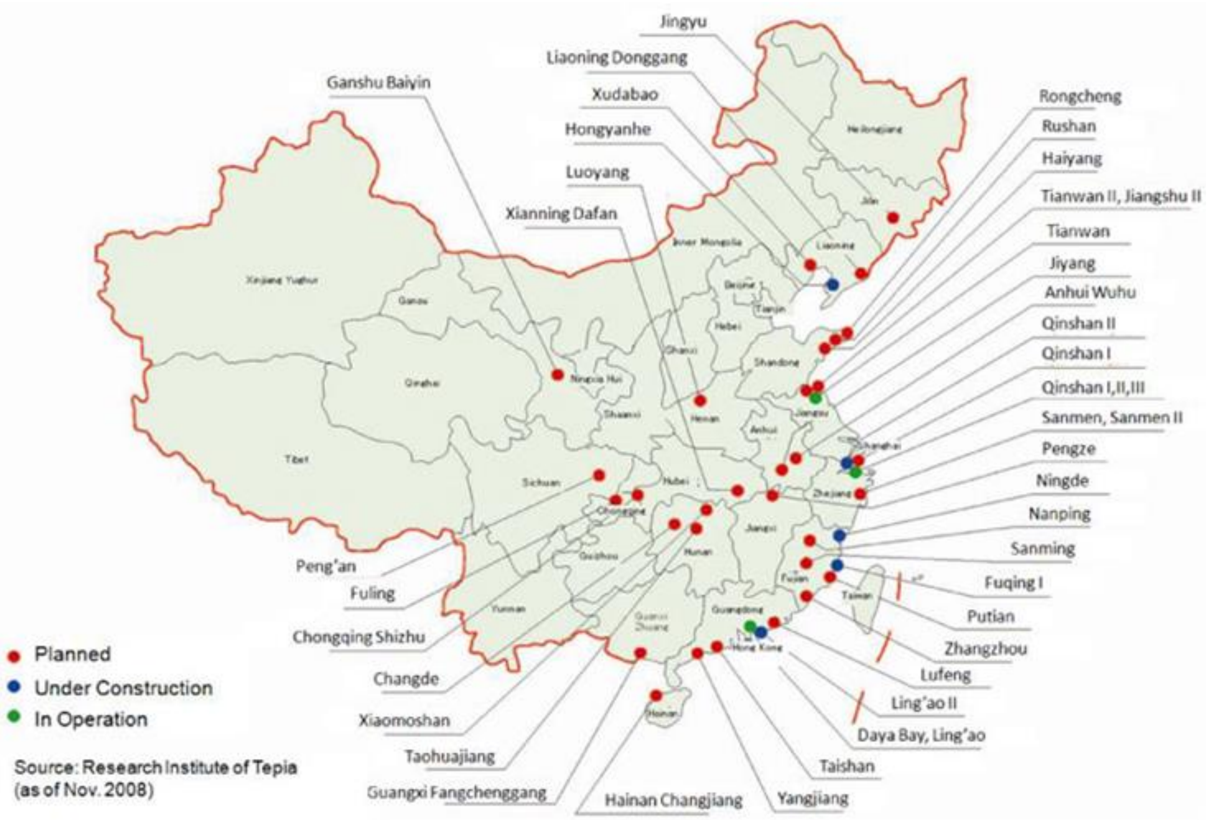
Sources: CNNC; Global Nuclear Association, BNP PARIBAS

The IAEA projects that global nuclear installed capacity would increase from current level of 371.7GW to 400.6 GW in low project case and almost 700GW in high project case. The majority of increased capacity comes from Non-OECD Asia, namely China and South Korea (International Atomic Energy Agency, 2014). Actual installation is believed to be somewhere in between these two projections.

According to the World Nuclear Association, by May 2015 there are 26 nuclear power reactors in operation (17GW), 24 under construction, and more about to start construction in mainland China. This is almost 40% of the world’s total capacity currently under construction. However, nuclear is only 2% of the country’s total installed capacity. This is not only much lower than other major nuclear nations, but also lower than other power generation technologies such as coal and wind. Therefore the government targets to build 58 GW (net) of nuclear power plants in operation by 2020, and 30 GW under construction at that time.

With Chinese ambitious target to reach greenhouse gas emission peak by 2030, nuclear provide a cost-effective alternative to the country’s dominate coal fired power plants. Nuclear power has one more important advantage compared to coal fired power plants: nuclear power plants are built along the east coastal area where economic development and load centres are located (see figure below for the distribution of Chinese nuclear power plants).

Figure 11 Geographic distribution of nuclear plants in China as of 2008



Sources: Research Institute of Tepia

Chinese nuclear power technology has largely achieved self-sufficiency in reactor design and construction, as well as other aspects of the fuel cycle (World Nuclear Association, 2015).

Being self-sufficient in nuclear technology is a national strategy that is not only important to energy security, but more importantly it will stimulate high-end technology-intensive nuclear component manufacturing in China and opens up the door for export Chinese nuclear technology and equipment to the global market.

The #1 reactor of Fangjiashan NPP which was commissioned in November 2014 has achieved 80% self-sufficiency in manufacturing key components domestically. As more and more nuclear power plants are being built in China over the next decades, the self-sufficiency level will increase gradually.

The Chinese nuclear technology is largely based on Westinghouse AP1000. Westinghouse has agreed to transfer technology to SNPTC, one of the three state-owned nuclear majors in China over the first four AP1000 units so that SNPTC can build the following ones on its own. In

2014 SNPTC signed a further agreement with Westinghouse to deepen cooperation in relation to AP1000 and CAP1400 technology globally.

Nuclear and high speed train have become the two pillars of Chinese machinery export for the state. The government has been actively promoting the export of Chinese nuclear and high speed train worldwide backed by large Chinese foreign reserves. It is estimated that China has the capability to build 10 nuclear power plants each year but will only install 2-3 annually in the next decades. In January 2015 the cabinet announced new incentives and financing for industry exports, particularly nuclear power and railways

Table 3 Chinese nuclear export

Country	Plant	Type	Est. cost	Company	Status, financing
Pakistan	Chasma 3&4	CNP-300	$2.37 billion	CNNC	Under construction, Chinese finance 82% of $1.9 billion
	Karachi Coastal	Hualong One	$9.6 billion	CNNC	Planned, $6.5 billion vendor finance, maybe 82% China finance
Romania	Cernavoda 3&4	Candu 6	€6.5 billion	CGN	Planned, Chinese finance
Argentina	Atucha 3	Candu 6		CNNC	Planned, with local involvement and $2 billion Chinese financing
	Atucha 4 or other site	Hualong One		CNNC	Vendor financing envisaged
UK	Bradwell	Hualong One		CNNC/CGN	Financed by China
Turkey	?	AP1000 or CAP1400		SNPTC or CGN	Exclusive negotiation
South Africa		HTR600		CNEC	

Source: World Nuclear Association

So far there are 5 plants being planned/under construction for Pakistan, Romania and Argentina. China is also in talks with UK, Turkey and South Africa for potential nuclear power technology export. Eecently the largest nuclear firms went public in the stock market which raised billions of dollars to power nuclear projects domectically also finance the export of nuclear power plants that are coming online very soon.

With Chinese financing, cheap construction and equpment costs and engineering knowhow and experienced workers, Chinese nuclear technology has substantial competitive advantage compared to its rivals in the global market in the decades to come.

3 Literature Review

LCOE has been a major tool to evaluate the cost of generating electricity and compare the cost across technologies and countries. Ample of research has been done every year to study the LCOE of different power generating technologies in different countries/ regions. This is especially true for renewable power technologies since the costs of these technologies have declined rapidly in the past few years and much interests have been on how much these costs have decreased and when they are going to reach grid parity with conventional thermal power or nuclear in some countries.

(IRENA, 2015) in January 2015 published its 2014 version of LCOE calculations for 2014 and predictions for 2025 for renewable power technologies including wind, solar PV, CSP, hydropower, biomass and geothermal for major countries and regions. The model used discounted cash flow (DCF) method to calculate LCOE. Lifetime costs consisted of initial investment expenditure, O&M and fuel costs. It did not include factors such as taxes, subsidies and other incentives. However, the focus of the study was past cost development and current LCOE figures in different regions. The projection to 2025 was based on simple model and assumptions.

(Fraunhofer Institute for Solar Energy Systems ISE, 2013) also presented a study on the LCOE of various power generation technologies including solar PV, wind, biogass, coal, CCGT, Concentrating Photovoltaics (CPV) and Concentrating Solar Power Plants (CSP) in Germany. It presented the current LOCE as well as projection into 2030 by incorporating learning curves and market projection of deployment of these technologies up to 2030.

(ISE, 2015) in February 2015 published another study commissioned by Agora Energiewende on current and future cost of Photovoltaics globally. They did a study on historical learning rates of solar PV and calculated LCOE of solar PV up to 2050. It was concluded that the LCOE could reach between 4 and 6 euro ct/kWh in 2050. The key drop of cost of solar PV will not come from the decline of costs associate with panels or BoS, but more from the decrease of financing costs and regulatory environment.

(Tidball, Bluestein, Rodriguez, & Knoke, 2010) compared technical performance characteristics, cost characteristic and LCOE of different energy technologies used in six models performed by six different leading institutions. Technologies covered by these studies include coal, gas, nuclear, biomass, geothermal, wind and solar. The study concluded that less mature technologies, such as solar thermal and PV, and those that are heavily dependent on site conditions, such as geothermal, tended to have much higher variations in overnight capital costs than matured technologies such as coal and gas fired plants. Using a uniformed model with inputs from each study covered, they found out that there were large variations in calculated LOCE across different studies. Therefore there is a need to reconcile different data sets and approaches in order to get more comparable and consistent cost calculations from different institutions.

So far most of the research has been focusing on the global scale or on development nations. Few studies on current and projected LCOE of power generation technologies have been performed specifically for China.

(Ouyang & Lin, 2014) did a recent study on LCOE for renewables in China and compared the level of LCOE with level of tariff in China in order to derive the required subsidy for renewables. They concluded that the current FIT in China can only cover the LCOE of wind (onshore) and solar photovoltaic energy (PV) at a discount rate of 5%. Subsidies to renewables-based electricity generation, except biomass energy, still need to be increased at higher discount rates.

(Yuan, Sun, Zhang, & Xiong, 2014) did a similar research of current LCOE level but only on distributed solar PV projects. They found out that under existing tariff and subsidy policy, at the condition of 100% own consumption, only industrial/commercial projects in regions with best resource (1500 h/year) could possibly make economic sense at current tariff of 1.36 CNY/kWh.

Given the increasing importance of China in the global energy development path, it is necessary to do a more thorough study on the projected cost of energy in China in the long term.

4 Methodology

The quantitative part of this research will try to forecast the cost of power generation technologies including coal, gas, wind, solar PV and nuclear in China from 2015 to 2035. The cost measures will be Total Overnight Cost (TOC) and Levelised Cost of Energy (LCOE). These costs are derived using revised Cost Project Model from Statkraft to fit this research. The model is based on the current benchmark cost of generation, incorporating different learning rates and convergence effect that are also related to macroeconomic factors, and therefore projecting future cost of generation for each technology/country.

4.1 Structure of the Research

In practice, the research was structured in the following steps:

- Define Analysis Framework
- Benchmark Costs Collection
- Supply Chain Fundamentals
- Global and local Content in Labour and Materials
- Learning rates
- Macroeconomic Drivers
- Scenario Analysis
- Conclusion

4.2 Data Collection

Data were collected from three main sources: publications from national/multinational agencies on price levels and macroeconomic factors, previous studies on learning rates and costs of energy, and operational and financial data on benchmark projects.

First of all, data on macroeconomic factors such as price levels and inflation rates were collected from renowned agencies such as OECD, World Bank or national authorities.

Forecast on future deployment of capacity for each technology was collected from renowned industrial agencies such as IHS and Bloomberg New Energy Finance. Although there are many predictions made by various institutions based on different assumptions and scenarios, we felt that it was important to use source from one institution for all technologies in order to ensure consistence in these predictions. The figure may not be consistent with actual future deployment, but the overall trend is to a large extend correct.

As the model is based on current cost of generation, it is therefore important to find operation and financial statistics for latest projects. This is also one of the biggest parts of the research that took most time to compile. In summary, 5 coal fired power plants, 3 CCGT plants, 8 wind farms and 7 solar PV projects were identified and costs and operational data were obtained. Most of these plants were commissioned later than 2012 and some of them were not yet constructed. Cost and operation data were quoted from Feasibility Study Reports (FSAs) of these projects. These FSAs were submitted to either national or provincial Development and Reform Committee before they could get permission to build these projects. Therefore these FSAs were made on average 2 years before actual construction started for the project.

All cost data were then converted into US dollars at the time of conversion and inflated/deflated to 2015 price level.

4.3 Total Overnight Costs

Total Overnight Cost (TOC), sometimes also referred as Overnight Capital Cost, is the cost to construct a power plant assuming no interest is incurred during construction, as if the plant is built "overnight". Because it does not take into consideration financing costs, it is a very useful cost measure that can be compared across technologies and countries without having to consider different leverage ratio, interest rate and construction time for different power generation technologies and engineering capability of different countries.

In general, as summarized by US Energy Information Administration (EIA), TOC ($/MW) can be broken down into the following segments:

"Civil and structural costs: allowance for site preparation, drainage, the installation of underground utilities, structural steel supply, and construction of buildings on the site.

Mechanical equipment supply and installation: major equipment, including but not limited to, boilers, flue gas desulfurization scrubbers, cooling towers, steam turbine generators, condensers, photovoltaic modules, combustion turbines, and other auxiliary equipment.

Electrical and instrumentation and control: electrical transformers, switchgear, motor control centers, switchyards, distributed control systems, and other electrical commodities.

Project indirect costs: engineering, distributable labor and materials, craft labor overtime and incentives, scaffolding costs, construction management start up and commissioning, and fees for contingency.

Owners costs: development costs, preliminary feasibility and engineering studies, environmental studies and permitting, legal fees, insurance costs, property taxes during construction, and the electrical interconnection costs, including a tie-in to a nearby electrical transmission system." (Energy Information Administration (EIA), 2013)

Normally a total investment is quoted in a FSA. Therefore TOC can be calculated as:

$$TOC = TI - IDC - other\ deductibles \tag{1}$$

Where TI is the total investment of a project. IDC is the interest during construction. Other deductibles are assumed to be zero in this research.

The above TOC equation is used to calculate static TOC at a given point of time. However, in order to forecast future TOC, TOC has to be broken down into local and global components, and learning rates and price escalation factors for both local and global components have to be included.

$$TOC = [TOCg * GLRcum * Global\ PPP\ Scaling\ Factor] + [TOCl * LLRcum * Local\ PPP\ Scaling\ Factor] \tag{2}$$

Where TOCg is the global TOC component and TOCl is the local TOC component, GLRcum is the global cumulative learning rate and LLRcum is the local cumulative learning rate and scaling factors are the PPP/RER values on the global and local basis that integrates the price increase following the Balassa-Samuelsson effect mentioned in the next section.

As shown in equation (2), TOC is broken down into local and global components. Local cost component is linked to local learning rate while global cost component is linked to global learning rate. For a non-price setting country, local cost component is a relatively smaller part of total TOC that usually includes non-tradable items such as labor, land, permitting and licensing, electricity etc. Global cost component includes equipment, R&D etc that are more or less the same and move at the same rate globally.

Cumulative learning rate is represented by the product of cumulative deployment of capacity and learning rate for each technology. Therefore global learning rate is the product of accumulative deployment of installed capacity globally and global learning rate for each technology, while local learning rate is the product of accumulative deployment of installed capacity locally and local learning rate.

Simply summing the product of cost component and its learning rate is still not enough as it does not take into account changing price levels as represented by Purchasing Power Parity (PPP) adjusted by real exchange rate. Therefore in order to calculate future TOC, cost component will be adjusted both by its relative learning rate as well as local or global price levels. Some countries will see a rising real price level while other countries might experience fluctuating price level. Therefore TOC will not always decrease as we will see in the result of the analysis.

4.4 LCOE

LCOE ($/kWh) is one of the most commonly used measure of cost of electricity for policy marker, research institutions and corporations that aim to derive long term investment strategies. It is used to compare lifetime costs of electricity across technologies and countries. LCOE is also a “break even” price that investors have to charge on electricity output in order to justify the investment by making the project NPV to be zero. Therefore by comparing wholesale electricity prices and LCOE it can be concluded whether a particular technology has reached grid parity or not.

Basic formula to calculate LCOE for any technology:

$$LCOE = \frac{Total\ lifetime\ cost\ of\ electricity\ production}{Total\ lifetime\ energy\ production}$$

The major components of lifetime cost of generating electricity from a power plant can be broken down into CAPEX, Operating and Maintenance (O&M) and fuel costs. Depending on the purpose of study, technology under focus and regulatory regime of projects, other costs such as interests, tax, salvage value, carbon emission costs etc could also be included in the calculation of LCOE.

The IEA and OECD used the following formula for LCOE in their cost projection:

$LCOE = P_{Electricity} = \sum_t((Investment_t + O\&M_t + Fuel_t + Carbon_t + Decommissioning_t)*(1+r)\hat{}t) / (\sum_t(Electricity_t*(1+r)\hat{}t))$

Where $Electricity_t$: The amount of electricity produced in year “t”;

$P_{Electricity}$: The constant price of electricity;

(1+r)^t: The discount factor for year “t”;

$Investment_t$: Investment costs in year “t”;

$O\&M_t$: Operations and maintenance costs in year “t”;

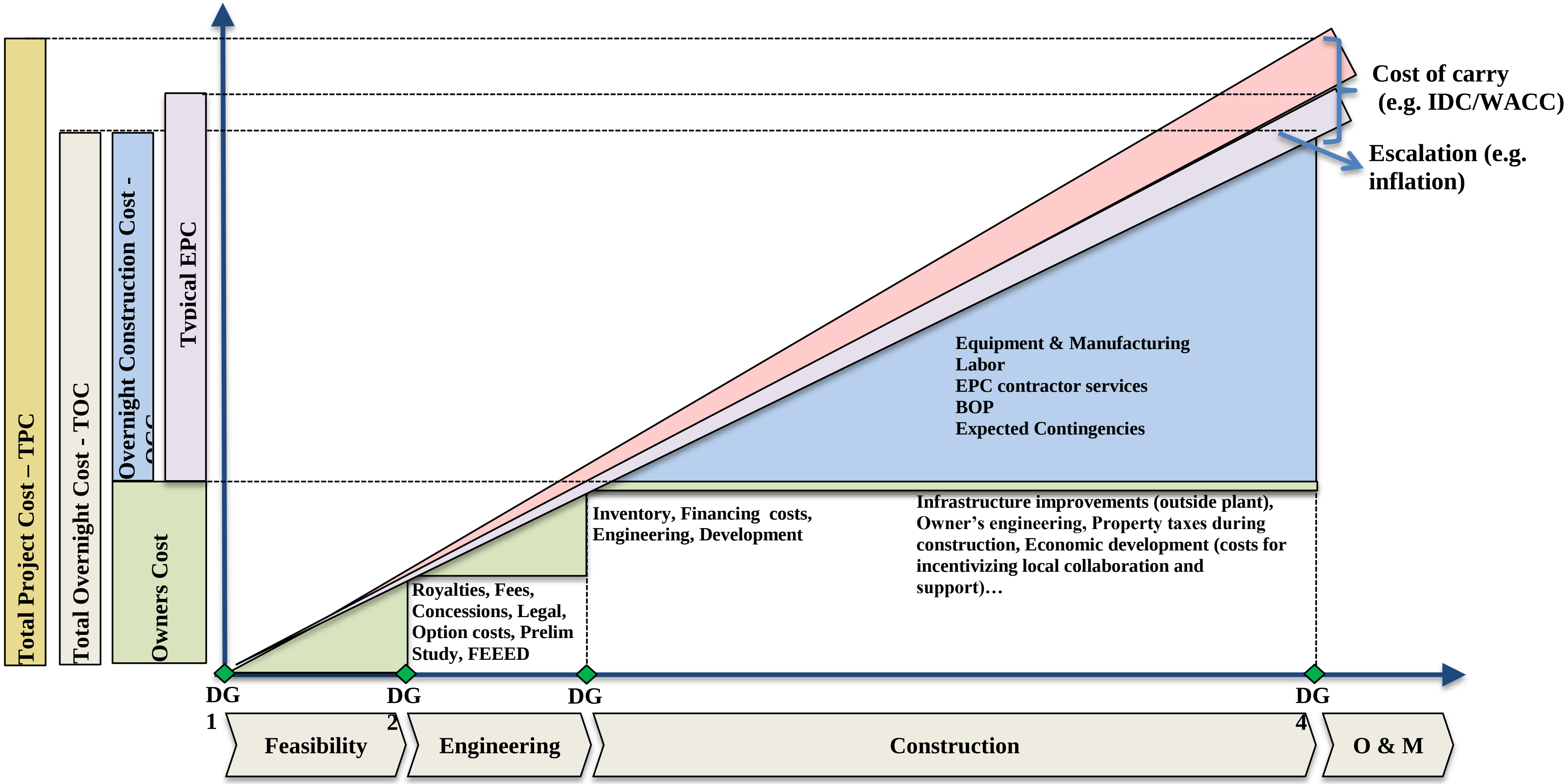
$Fuel_t$: Fuel costs in year “t”;

$Carbon_t$: Carbon costs in year “t”;

$Decommissioning_t$: Decommissioning cost in year “t”.

(International Energy Agency, OECD Nuclear Energy Agency, 2010)

Figure 12 CapEx of a development project



Source: Statkraft

The Fraunhofer Institute for Solar Energy Systems ISE which has published LCOE for solar energy for many year, on the other hand calculated LCOE with the following formula:

$$LCOE = \frac{I_o + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

LCOE: Levelized cost of electricity in Euro/kWh

$I_{0:}$ Investment expenditures in Euro

A_t: Annual total costs in Euro in year t

$M_{t,el}$: Produced quantity of electricity in the respective year in kWh

i: Real interest rate in %

n: Economic operational lifetime in years

t: Year of lifetime (1, 2, ...n)

(Fraunhofer Institute for Solar Energy Systems ISE, 2013)

No matter how these formulas may look very different, they all apply the same basic formula as presented in the previous page. The only difference lies in whether each formula takes into account factors such as degradation, tax, depreciation, salvage value etc.

For this particular study, since we are comparing across different power generation technologies, and we focus on purely technological costs but not taxes, subsidies etc, we only include three major cost components: CAPEX, Operating and Maintenance (O&M) and fuel costs.

$$LCOE = \frac{TOC + \sum_{t=1}^{n} \frac{M_f + M_t + F_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$$

TOC: total overnight cost

M_f: fix O&M expenses

M_t: variable O&M expenses at year t

F_t: fuel costs at year t

E_t: electricity generated in year t

i: interest rate (WACC)

n: lifetime of the power plant

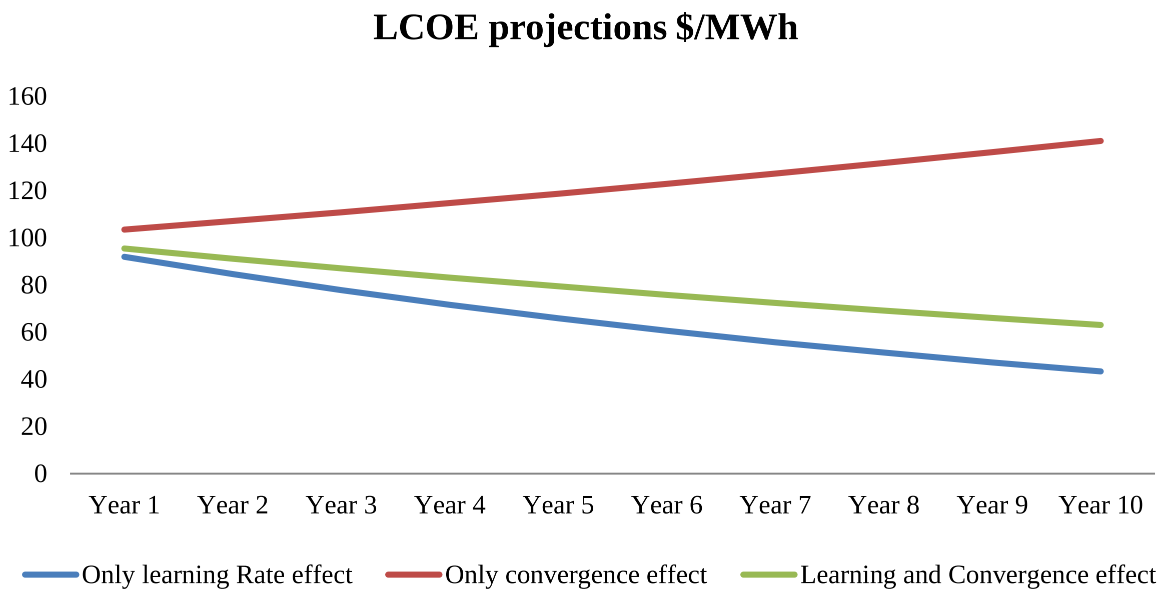
4.5 Cost Projection Model

The cost project model attempts to predict how the cost of generating electricity will develop over time by capturing two effects in one;

- Learning curve effects lowering costs over time
- Convergence effect increasing emerging countries' costs over time

The overall combined effect of the two could lead to either lowering or increasing of cost of generating electricity depending on which of the effect prevails.

Figure 13 Effects of learning rate and convergence on LCOE



Source: Statkraft

4.5.1 Learning Curve

The terms of learning curve and experience curve are usually used interchangeably. Bruce D. Henderson and the Boston Consulting Group (BCG) first developed the experience curve and used it in analyzing the effect of accumulated units produced on the decline of unit production cost for a major semiconductor manufacturer in the 1960s. The findings from the study confirmed that company's unit production costs would fall by a predictable amount—typically 20 to 30 percent in real terms—for each doubling of "experience," or accumulated production volume (BCG, 2013).

There are various forms of expression for experience curve. A basic experience curve can be expressed as (L. Neij, 1999) and (Kiss & Neij, 2011):

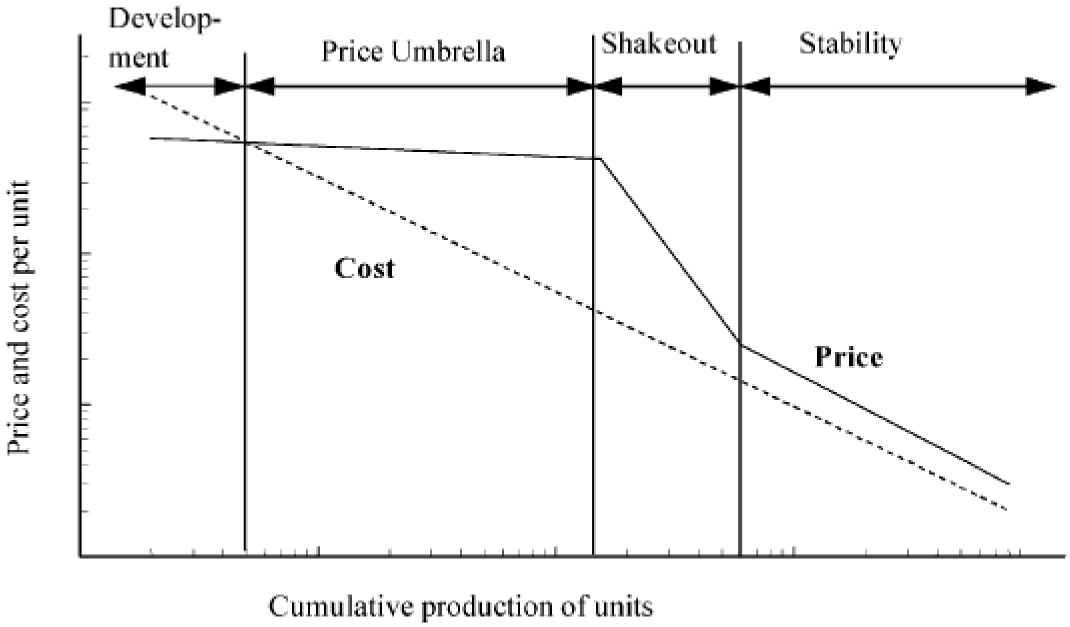
$C_{cum} = C_0 * Cum^b$

$$logC_{cum} = logC_0 + b * logCum$$
$$PR = 2^b$$
$$LR = 1 - 2^b$$

where C_{Cum} is the cost per unit; C_0 the cost of the first unit produced; Cum the cumulative (unit) production; b the experience index; PR the progress ratio and LR the learning rate.

Graphically, the learning by doing effect can be expressed in the figure below.

Figure 14 Relationship between costs and prices during market introduction of a new product



Source: adopted from Boston Consulting Group (1972)

Ever since its emergence, experience curve has proven to be very useful for corporate strategy. Many firms apply the concept to predict future costs and devise their strategy accordingly. Governments also apply experience curve in designing industrial strategy in order to promote the development of certain key industry. It has also been widely applied in the energy sector for a long time. (de la Tour, Glachant, & Meniere, 2013) in a recent research predicted the cost of PV modules out to 2020 using experience curve models. The model predicted that there would be a 67% decrease of module price from 2011 to 2020. (Bhandari & Stadler, 2009) used experience curve and progress ratio to analyze future cost of solar PV module compared to wholesale electricity prices to predict when solar PV would be in grid parity. (Ferioli, Schoots, & van der Zwaan, 2009) broke the learning-by-doing for an entire energy technology into learning curves for single components to derive one comprehensive learning curve for the total product, and therefore they argued that cost reductions may not continue indefinitely and that well-behaved learning curves do not necessarily exist for every product or technology.

The cost project model further divides learning rate into global learning rate and local learning rate for each technology. This will enable the study to take into consideration of the different deployment rate of installed capacity of particular technology in each country and its resulted different progress ratio. This means that local component of TOC will decline at the local learning rate while global component of TOC will decline at the global learning rate.

To derive the learning rate for power generation technology is not that straight forward. It depends on the timespan of data which is used for fitting the trendline, geographical scope of the cost estimates as well as accuratedly collected installations. In this study we will mainly make our learning rates reference to the research done by Lena Neij (Lena Neij, 2008).

A recent study by Fraunhofer ISE long-term PV learning rate is between 19% and 23% depending on the timeframe of the fitting, therefore leading to an average learning rate of 20.9 percent (Fraunhofer ISE, 2015). (de la Tour et al., 2013) also analyzed many previous studies on learning rate for PV and concluded that the average learning rate used by these studies was 20.9%, which is in line with the figure used by Fraunhofer ISE. For a list of these studies and their respective learning rates, refer to the original paper by de la Tour et al (2013). (Lena Neij, 2008) on the other hand, also did a comprehensive study on learning rates used by other researchers, and came to the conclusion that solar PV had a learning rate of approximately 20%.

For onshore wind, (Kobos, Erickson, & Drennen, 2006) estimated that learning rate was around 14.2% for global wind technology. (Ek & Soderholm, 2010) analyzed that for Denmark, Germany, Spain, Sweden, UK and found that wind had a learning rate of approximately 17.1%. Some others, such as (Kahouli-Brahmi, 2009) derived a much higher learning rate for global wind technology which was as much as 17.1% to 31.2%. In this research we adpot a global learning rate of 17% for onshore wind.

Studies on learning rates for thermal plants are very limited. (Rubin, Yeh, Antes, Berkenpas, & Davison, 2007) used 2-5% for CCGT. They They suggest learning rates of 2–5% for pulverized coal (PC) and natural-gas combined-cycle (NGCC) plants with post-combustion CO2 capture, coal-based integrated gasification combined-cycle (IGCC) plants with pre-combustion capture, and coal-fired oxyfuel combustion for new PC plants. (Lena Neij, 2008) adpoted a learning rate of 5% for all types of coal-fuelled power plants including systems for decarbonisation and carbon sequestration. In this study we assume a global learning rate of 5% for CCGT and 5% for advance coal fired technologies.

(Lena Neij, 2008) suggested a learning rate of 3-5% for nuclear. However, given the fact that the study was done before the Fukushima accident, it is reasonable to assume that countries such as Japan and Germany will not invest as much as they used to on nuclear power generation technology in future. Therefore we assume a lower learning rate of 1% for nuclear in this study.

There is no exact way to calcualte learning rates precisely and therefore all the above learning rates should be seen as a best guess rather than the actual number.

4.5.2 Convergence effect

Convergence effect states that poorer economies‘ prices will tend to grow at faster rates than richer economies, and as a result, prices in the world will eventually converge.

Cost differences can mainly be explained by differences in:

- Labour costs
- Productivity
- Purchasing power parity
- Quality
- Taxes/transportation

In a competitive market, price (P) = marginal cost (C)

If productivity (A) is included, then unit cost:

$C_{(i,k)}=P_{(i,k)}/A_{(i,k)}$

For labour intense goods, price is represented by wages; for material intense goods, price is represented by ppp. Productivity can be represented by GDP/capita.

Cost of energy could vary a lot across different countries, as illustrated by figure 2. one of the key contributor to difference in LCOEs across/with in countries are Non-tradable (NTs) goods and services. A macroeconomic study was conducted by another student as part of this broader project to study the effect of tradable and non-tradable items on the cost differentials of the same technology in different countries (refer to another NHH student Shubam Gupta’s master thesis report).

In his research, Gupta found out that cost of NTs such as land, construction services, utilities such as water, labour, etc. variy significantly across the countries due the fact that their prices are determined by local market equilibrium. Non-tradables are produced and consumed locally, while tradable items could be imported or produced locally but subject to global competition. Therefore prices of traded goods are determined based on international supply and demand equilibrium, and are subjected to law of one price and Purchasing Power Parity (PPP) principles, the prices of NTs are determined by local market equilibrium. The cost project model captures the variations in prices of NTs across countries. The model can factor in the convergence effect by incorporating a trajectory of the price development of NTs upto 2035 as supplied by user (for exact description of the NTs and convergence effect, refer to Shubam Gupta's paper).

Therefore to incorporate the convergence effect, first we first to decide the price setting country for each technology through 2035. Then these macroeconomic factors will be used to simulate the convergence of price levels of other countries to that price setting country. Out of the first power generating technologies, China is assumed to be the price setting country for all five technologies except CCGT which we assumed that US would be the price setting country given that shale revolution is pushing US to replace coal fired power plants with gas fired plants.

4.5.3 Macroeconomic Factors

As mentioned in the previous section, macroeconomic factors such as PPP and foreign exchange rates serve as proxy for prices of tradable and non-tradable items in the cost of each technology. After price setting country is selected, the model could simulate the convergence effect so that price levels will converge to that of the price setting country.

Table 4 Price levels in covered countries

	PPP (in local currency/USD)/Fx rate (local currency/USD)							
	Source	2010	2015	2020	2025	2030	2035	2050
USA	OECD	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chile	OECD/IHS	0.70	0.59	0.68	0.70	0.70	0.71	0.72
Peru	Chile	0.70	0.59	0.68	0.70	0.70	0.71	0.72
Turkey	OECD	0.63	0.57	0.66	0.73	0.77	0.80	0.83
Brazil	OECD	0.98	0.98	0.82	0.76	0.70	0.69	0.70
China	OECD/smoothing	0.64	0.69	0.71	0.72	0.73	0.74	0.76
India	OECD/smoothing	0.40	0.43	0.47	0.50	0.54	0.58	0.72

4.6 Scenario Description

Scenarios present different pathways to the future of global and local energy landscape, driven by technological development, economic growth, climate focus and regiment, innovation and security of supply, as well as demand and demographics. Therefore it is important to define and develop different forecasts based on different scenarios so that the results are robust to cater for actual development.

Based on different predictions/assumptions on cumulative capacity deployment and cost of capital for different technologies in China, this study defines three scenarios: base case scenario, low WACC case scenario and current case scenario.

Base Case Scenario

In the base case, prediction on Chinese cumulative capacity deployment quoted from IHS was adapted. This is the cumulative new deployment capacity without taking into account of netting of decommissioned capacity.

Table 5 Cumulative capacity deployments under base case scenario

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Coal-Fired	872	966	1029	1092	1129
Gas-Fired	60	108	162	230	303
Wind	107	193	279	361	422
Solar PV	35	84	145	208	270
Nuclear	36	71	104	146	199

Source: IHS 2015

Cost of capital defined by WACC as used by Bloomberg New Energy Finance (BNEF) was adapted in the base case scenario. The WACC for solar PV, wind, natural gas and coal plants are 8.0%, 7.9%, 7.4% and 7.4% respectively. We assume a WACC of 7.4% of nuclear as well so that it is comparable to that of conventional power plants such as coal and gas fired power plants.

Table 6 WACC under base case scenario

Technology	Debt Ratio	Cost of Debt	Cost of Equity	WACC (pre-tax nominal)
	%	%	%	%
PV - c-Si	70%	7.18%	10.00%	8.0%
Wind - onshore	75%	7.18%	10.00%	7.9%
Natural gas CCGT	80%	6.73%	10.00%	7.4%
Coal fired	80%	6.73%	10.00%	7.4%
Nuclear	80%	6.73%	10.00%	7.4%

Source: BNEF 2015 & own assumption for nuclear

Low WACC Case Scenario

Note that in the base case scenario, WACCs for renewable power are higher than that of conventionals. WACC represents the required return from banks and project sponsors which is adversely related to the perceived risk of the technology of the project. Under current market condition in China, renewables such as wind and solar may still be perceived riskier than conventional power technologies, even though the market has improved substantially in the past few years for renewables.

However, we are witnessing a totally different market development in Europe where renewable power has been deployed for a longer time and at a larger scale. As a result of the market reform and higher penetration of renewables in the grid, as well as stagnating demand, conventional power technologies such as coal, gas and nuclear are being perceived as much riskier investment by investors compared to renewables. In addition, the current near zero interest rate due to expansionary monetary policy in the US and Europe are putting much pressure on the yield of investments in traditional infrastructure projects. For example, institutional investors that have very low cost of capital such as pension funds, insurance, Yieldcos and private equity are currently rushing into the solar PV market in the UK because of perceived low risk and higher returns that can meet their now seen as higher constant return requirement. These institutional money has driven up the prices of these assets and therefore lowered their expected return/cost of capital.

The same is happening also in offshore wind sector which just over several years ago was still perceived as very risk projects. However, we are seeing that pension funds (for example Canadian Pension Funds) and institutional investors are more and more comfortable with the investment in offshore wind projects in NW Europe.

Therefore we predict that the cost of capital for renewables will decline to that below the level of conventional power technologies in a very short run in China as it is become in Europe. Indeed recent development in solar PV sector has proved that. A leading Chinese insurance company Huaxia Insurance confirmed in May 2015 that the insurance firm will invest along with United Photovoltaics in a portfolio of 1GW solar PV projects in China. As a result, in the Low WACC case scenario, WACC for wind and solar was assumed to be 7% compared to 7.4% for coal, gas and nuclear.

Table 7 WACC under low WACC case scenario

Technology	Debt Ratio	Cost of Debt	Cost of Equity	WACC (pre-tax nominal)
	%	%	%	%
PV - c-Si	80%	6.73%	8.00%	7.0%
Wind - onshore	80%	6.73%	8.00%	7.0%
Natural gas CCGT	80%	6.73%	10.00%	7.4%
Coal fired	80%	6.73%	10.00%	7.4%
Nuclear	80%	6.73%	10.00%	7.4%

Source: BNEF 2015 & own assumption for nuclear

The cumulative deployment capacity in Low WACC case scenario is assumed to be the same as that in the base case scenario.

Current Case Scenario

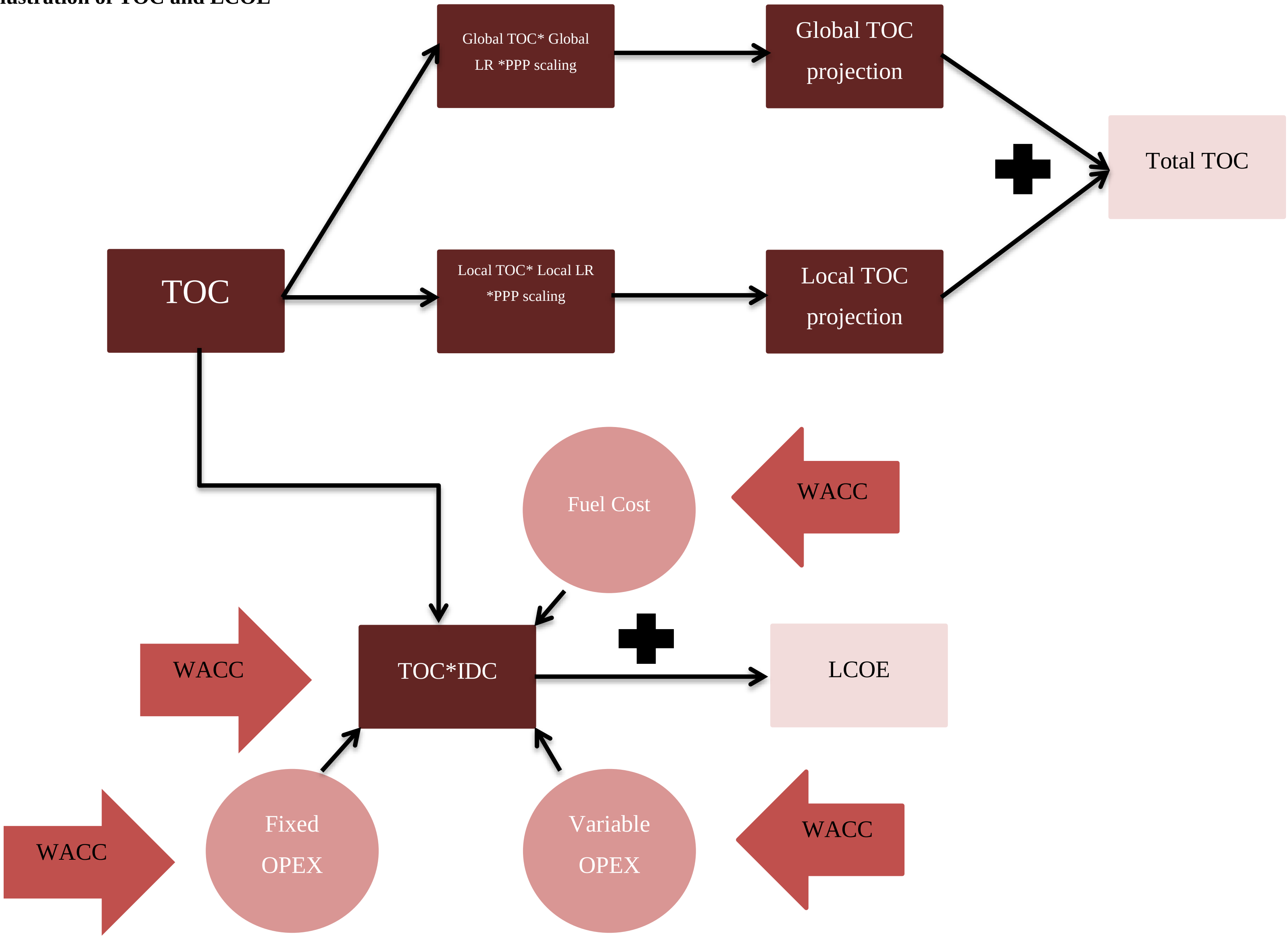
In the current case scenario, the cost of capital is defined the same as in the Low WACC case scenario. However, cumulative capacity deployment forecast for solar PV is different from the forecast of IHS. Beijing in March 2015 announced a solar installation target of 17.8 gigawatts (GWs) for 2015, which is an increase of over 70% from 2014. The government is targeting to install 100GW of solar PV by 2020. Therefore, bases on the faster deployment of solar PV in China, another scenario is defined that will see much more solar PV being installed in China towards 2035. In the current case scenario, it is predicted that China will install 18GW of solar PV each year until 2035.

Table 8 Cumulative capacity deployments under current case scenario

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Coal-Fired	872	966	1029	1092	1129
Gas-Fired	60	108	162	230	303
Wind	107	193	279	361	422
Solar PV	45	100	225	315	405
Nuclear	36	71	104	146	199

Source: IHS 2015

Figure 15 Illustration of TOC and LCOE



5 System cost projection and LCOE calculation

5.1 Total Overnight Cost

The table below shows the TOC of selected technologies in China. All cost data are expressed in 2015 dollars. Coal and CCGT have the lowest capital costs while nuclear has the highest capital costs among all technologies.

Table 9 TOC of selected technologies in China

Technology	TOC (M$2015/MW)
CCGT	0.60
Coal	0.60
Solar PV	1.41
Wind	1.36
Nuclear	3.50

Source: own illustration

The following tables present the source of TOC data for coal, CCGT, wind and solar PV projects in China. Looking at these tables, it is apparent that TOC has been decreasing over time (indicated by the Commercial Operations Date, COD) for most technologies. Not only does TOC decreases over time, it also decreases as project size goes up due to economies of scale and projects are becoming larger and larger over time.

Table 10 TOC of coal fired power plants in China

Name of project	**Technology**	**Capacity per unit** (MW)	**COD**	**Total Overnight Cost** (M$/MW)
Banji 2×1000MW units project	USC	1000	Sep-16	0.60
Ningxia Huadian Yongli Phase I Ultra-supercritical air-cooled turbogenerator project	USC	660	2017	0.65
Shishi Hongshan Thermal Power Plant Phase II	USC	1000	Unit 1: 2014 Unit 2: 2015	0.70
National average for projects commissioned in 2011and 2012	USC	1000	2011&2012	0.77
	USC	600		0.78
	SC	600		0.79
	SC	350		0.87
	Sub-critical	300		0.93
	CFB	300&below		0.85
Waigaoqiao Phase III ultra-supercritical coal-fired generation project	USC	1000	Unit 1: March 2008 Unit 2: June 2009	0.93

Source: own illustration

Table 11 TOC of CCGT in China

Name of project	**Capacity per unit** (MW)	**Total Installed Capacity** (MW)	**COD**	**Total Overnight Cost** (M$/MW)
Beijing Caoqiao CHP Project	350	838	Feb-13	0.54
Putian CCGT Phase I Project	390	1560	Unit 1: Dec 2008 Unit 2: April 2009 Unit 3: March 2010 Unit 4: July 2010	0.70
Zhongshan Jiaming CCGT Phase III	390	1170	2014	0.65

Source: own illustration

Table 12 TOC of wind projects in China

Name of project	**Capacity per Turbine** (MW)	**Total Installed Capacity** (MW)	**COD**	**Total Overnight Cost** (M$/MW)
Jishan Wind Farm	2	49.5	Oct-15	1.68
Baodingshan Wind Farm	2	48	Jul-05	1.49
Dapashan Wind Farm	2	48	Feb-15	1.57
Sandaojing Wind Farm	2	48	Feb-15	1.47
Wenbishan Wind Farm	2	40	Dec-14	1.62
Santanghu Wind Farm	1.5	49.5	2014	1.62
Beijing Guanting Wind Farm Phase III	1.5	49.5	2014	1.93
Inner Mongolia Eergetu Phase I Wind Farm		49.5	2008	1.97

Source: own illustration

Table 13 TOC of solar PV projects in China

Name of project	**Total Installed Capacity** (MW)	**COD**	**Total Overnight Cost** (M$/MW)
Xiangshui 100 MW Solar Project	100	Sep-14	1.59
Hongliuwa 50 MW Solar Project	51	2015	1.91
Jinzhai 150 MW Solar Project	150	End 2014	1.35

Daheigou 100 MW Solar Project	101	May-14	1.98
Wuwei 50 MW Solar Project	50	Dec-13	2.19
Wulate 40 MW Solar Project	40	Dec-13	2.04
Anhui Sansha 100 MW Solar Project	100	Oct-14	1.47

Source: own illustration

5.2 WACC

Weighted Average Cost of Capital (WACC) is a measure of the overall cost of capital in terms of both debt and equity. Project developer choose the optimal capital structure so that they will achieve the lowest cost of capital. WACC can be calculated as:

$$WACC = Debt\ ratio * Interest\ Rate * (1 - Tax\ rate) + Equity\ ratio * Required\ return\ on\ equity$$

Where equity ratio = 1- debt ratio.

Cost of debt is relatively stable and transparent. It is usually a premium plus interest rates on long term government bonds, depending on the term of the loan and risk profile of the project. The uncertainty with regard to WACC really lies in the assumption of leverage ratio and more importantly, the judgement on the cost of equity. Estimating the cost of equity is not that straightforward, and usually requires a lot of estimation and benchmarking.

In consideration of this uncertainty, most studies apply fixed 5%, 10% and sometimes 7% test WACC that applies to all technologies to see the competiveness of different technologies under the same WACC.

This study adopt the WACC numbers used by BNEF on Chinese power generation technologies, as presented in table 5 in the earlier section: 8.0% for solar PV, 7.9% for wind, 7.4% for CCGT and 7.4% for coal fired power plants. Based on the WACC for CCGT and coal fired power plant, we judge that nuclear in China will most probably have the same WACC as these for CCGT and coal fired power plant which is 7.4%.

However, as argued in the Low WACC case scenario, WACC for wind and solar PV will likely to drop to level below that of CCGT and coal fired power plants very soon. Therefore we proposed the Low WACC case scenario to take into account the changing dynamics in the cost of capital for renewable power project in China.

(International Energy Agency (IEA), 2014)

5.3 Learning Rates and Learning Bases

Global learning bases are based on the projected deployment of installed capacity for each technology globally from IHS, extrapolated to 2035.

Table 14 Global learning bases

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
IHS Coal-Fired	1901	2031	2168	2350	2530
IHS Gas-Fired	1582	1746	2019	2394	2848
IHS Onshore Wind	372	558	743	926	1093
IHS Solar PV	198	366	522	674	832
IHS Nuclear	411	447	487	531	583

Source: IHS 2015

Global learning rates were discussed in the previous sections. We choose the same local learning rate as the global learning rate, given the large scale of Chinese deployment and manufacturing capacity. China is the price setting country for all but CCGT. As for the breakdown of global and local cost component, as was discussed in the supply chain section, we give 50%-50% for CCGT, and 10% global, 90% local content for coal, solar PV and wind. For nuclear, we give 5% global content and 95% local content given the massive nuclear project pipeline in China and its export potential.

Table 15 Global and local learning rates and cost components

Technology	Global Learning Rate (%)	Local Learning Rate (%)	Global Cost Component (%)	Local Cost Component (%)
CCGT	5%	5%	50%	50%
Coal	5%	5%	10%	90%
Solar PV	20%	20%	10%	90%
Wind	17%	17%	10%	90%
Nuclear	1%	1%	5%	95%

Source: own illustration

Table 16 China Cumulative Capacity Deployments (GW)

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Coal-Fired	872	966	1029	1092	1129
Gas-Fired	60	108	162	230	303
Wind	107	193	279	361	422
Solar PV	35	84	145	208	270
Nuclear	36	71	104	146	199

Source: IHS 2015

5.4 Capacity Factor

Table 17 Capacity factors

Technology	Capacity Factor (%)	Availability (%)
CCGT	100%	90%
Coal	100%	90%
Solar PV	14%	99%
Wind	25%	93%
Nuclear	100%	85%

Source: own illustration

Unlike most other studies, in this study we define capacity factor as the theoretical maximum output given a technology, disregarding the actual load factors that may differ from capacity due to reasons such as curtailments. We further define availability as the percentage of time that the plant is able to produce electricity after necessary shutdown for repair, maintenance, refueling etc. Therefore the output of such hypothetical power plant will be the product of capacity factor and availability.

Coal fired power plants, CCGT and nuclear power plants serve as baseload and therefore their capacity factor is set to be 100%, meaning that they should be able to be allowed to generate full time when they are available. Solar PV has an average capacity factor of 14% given the average irradiation level in China. Wind has an average capacity factor of 25%.

Both CCGT and coal fired plants are assumed to have availability of 90%, meaning that down time will be 10% for possible repairs, maintenance and other operations. Solar PV has the highest availability given that solar panels do not need much repair or maintenance than other technologies. For wind projects, availability is assumed to be 93%, slightly less than global average due to the fact that the Chinese wind market is dominated by domestic turbine suppliers and domestically manufactured turbines used to suffer from more technical problems than leading international turbine suppliers.

Nuclear is assumed to have availability of 85% which is higher than load factors for existing nuclear power plants. However it is in line with the advertised maximum performance of planned Generation III + reactor designs (International Energy Agency, OECD Nuclear Energy Agency, 2010).

5.5 Fuel Prices

Wind and solar PV do not need fuel to produce electricity. Coal and LNG prices as well as uranium price were collected from BNEF up to 2025. Then these prices were interpolated to extend to 2035.

Table 18 Fuel costs

Fuel Prices ($/MWh)	2015	2025
Coal China	11	15
Gas China	28	34
Nuclear China	8	12

Source: BNEF 2015

5.6 OPEX

OPEX cost is broken down into fixed and variable OPEX. For solar PV and wind, we assumed no variable OPEX and only fixed OPEX. Coal and CCGT have both fixed and variable costs. For simplicity, we also assumed that for nulcear there was only variable costs.

Table 19 Fixed and variable OPEX rates

Technology	Fixed OPEX (k$/MW)	Variable OPEX ($/MWh)
CCGT	15.15	3.79
Coal	11.03	2.76
Solar PV	23	0
Wind	16	0
Nuclear	0	15.10

Source: own illustration

5.7 Other Assumptions

The following table summarizes some of the other assumptions with regards to the input of the cost projection model. Solar PV and wind both have lifetime of 25 years. CCGT and coal will be operational for 30 and 35 years respectively. Note that nuclear is assumed to have an operation lifetime of 60 years based on the fact that most nuclear power plants in the world would have an initial lifetime of 40 years and additional extension of 20 years.

Table 20 Other technical factors

Technology	Fuel Net Efficiency (%)	Economic Lifetime (yrs)	Construction Time (yrs)	Global Price Setting Country	Technology
CCGT	60%	30	2.5	USA	CCGT
Coal	45%	35	3	China	Advanced USC

Solar PV	100%	25	1	China	poly-Si
Wind	100%	25	1	China	onshore
Nuclear	33%	60	5	China	AP1000

Source: own illustration

In addition to the above input/assumptions, for calculating purely technological costs, curtailment was ignored in this study. It is assumed that China will develop enough high voltage transmission lines in a timely manner so that all new project will be grid connected and electricity generated will be fed into the grid. However, this may not be always true in China. Curtailment has long been a big obstacle to the profitability of the wind and solar PV industry in China. For instance curtailment rate for wind used to be as high as 18% in 2013, and gradually been reduced to less than 8% in 2014. However, in the first quarter of 2015 the curtailment rate has raised again to more than 20% due to larger deployment of renewable power in congested areas. Even though the Chinese government has planned to invest hundreds of billions in the coming decade on transmission capacity, it may still lag behind the deployment of renewables.

6 Discussion of Results

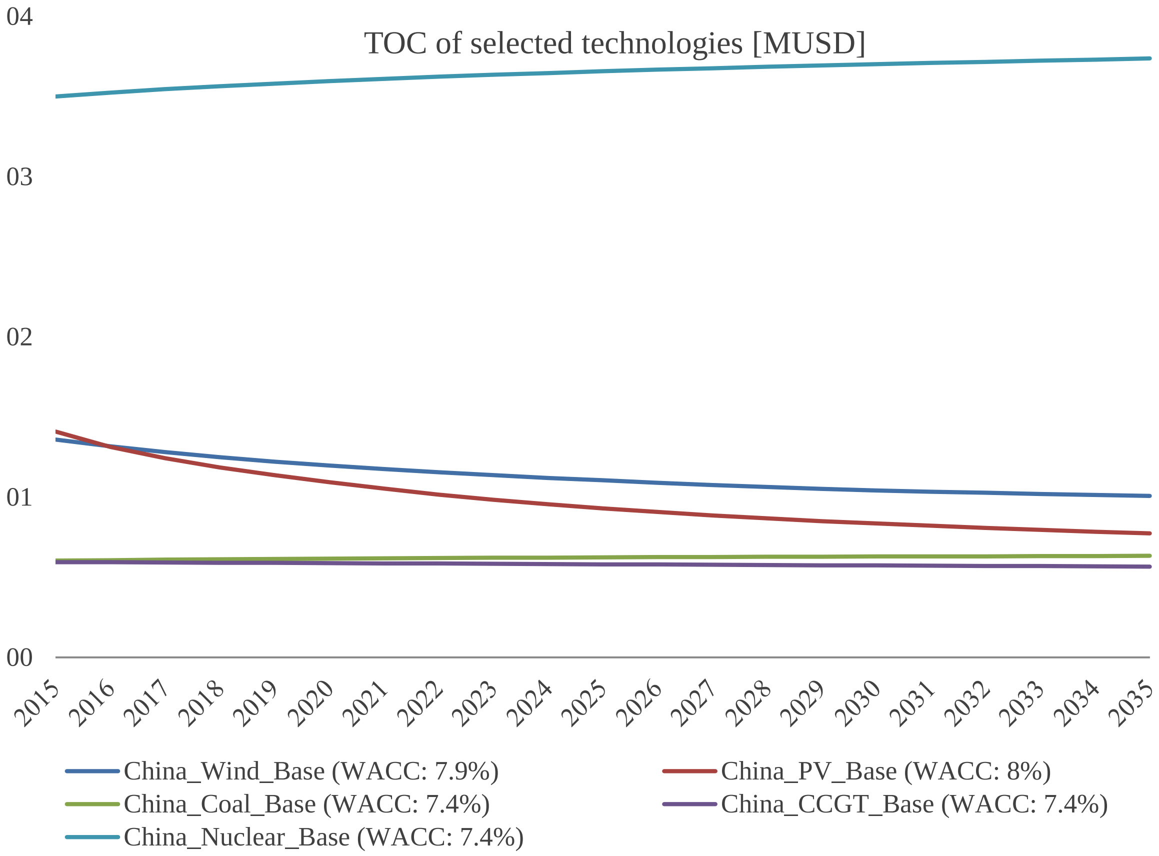
6.1 Modelling Results

6.1.1 Base Case Scenario

Total Overnight Costs were forecasted to 2035 for each of the technologies taking into account rising costs, local and global learning rate and content in China. Nuclear is the most capital intensive technologies among the five technologies studied. The TOC for nuclear is around $3.5 million/MW and is on a rising trend.

TOC for Coal and CCGT will largely remain stable throughout the time period. Solar PV and wind will see a substantial drop in capital costs due to experience curve. TOC for solar will drop the most, first below that of wind in 2016-2017, and then approaching that of coal by the end of 2015.

Figure 16 TOC of selected technologies in China in base case

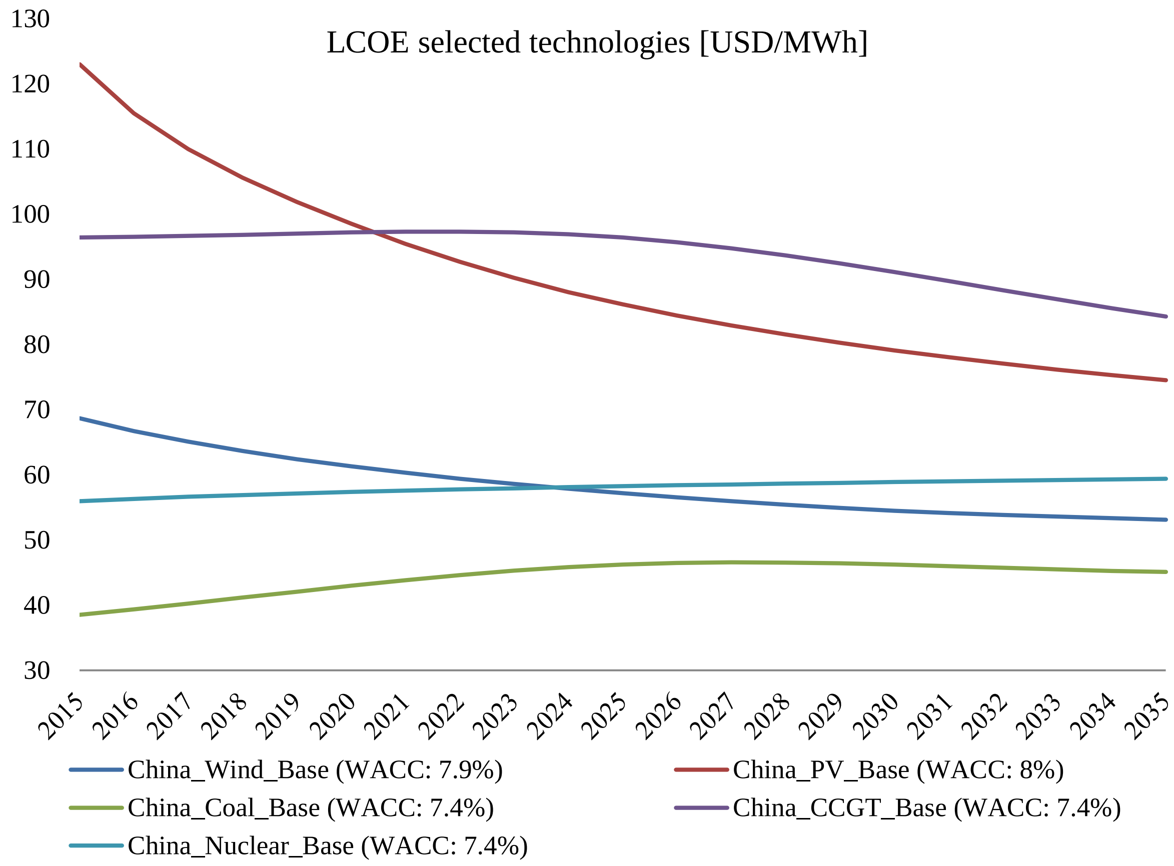


Source: Own illustration

The LCOE comparison displays very different pattern as compared to that of TOC. Even though nuclear has the highest TOC, its LCOE is one of the lowest, only higher than coal.

In the first case as WACC from BNEF was used, i.e. 7.9% for wind and 8% for solar PV, solar PV has the highest LCOE among all technologies, at more than $120/MWh. It also drops the most from level to around $80/MWh in 2035, lower than that of CCGT. LCOE for wind will also drop substantially so that it will be cheaper than nuclear by 2024. As expected, coal will still remain as the cheapest sources of electricity even until 2035. CCGT will become the most expensive source of electricity from 2020 after it surpasses that of solar PV. This is also in line with the current situation of CCGT development in China. Though Chinese government is promoting the replacement of coal by gas in north and east of China as these are the areas that suffer the most from air pollution caused by burning coal, it is not at its top priority to deploy CCGT in large scale. There is no long term strategy/ development plan from the government on gas plants as compared to nuclear, wind and solar PV.

Figure 17 LCOE of selected technologies in China base case scenario



Source: Own illustration

Table 21 LCOE of selected technologies in China base case scenario

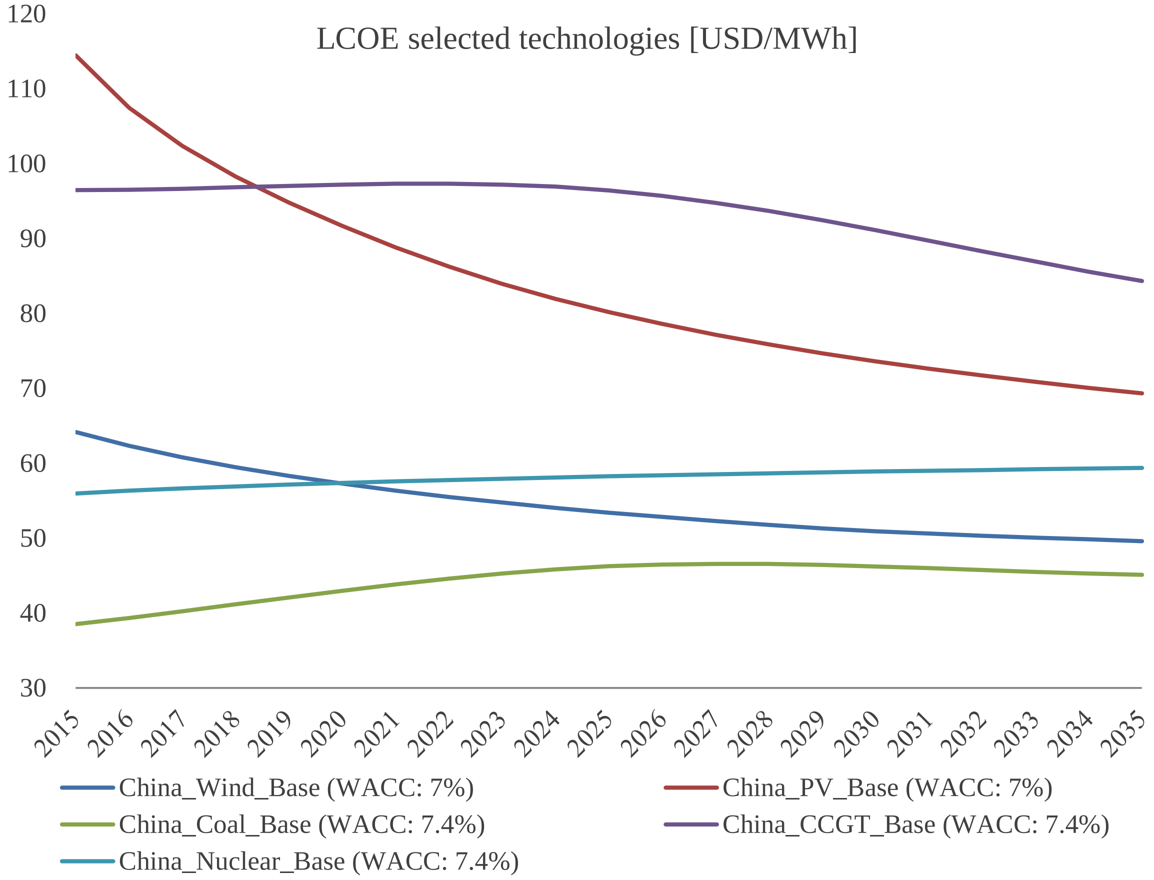
LCOE selected technologies [USD/MWh]	WACC	2015	2020	2025	2030	2035
Wind	7.90%	68.70	61.32	57.19	54.52	53.10
PV	8.00%	123.01	98.54	86.17	79.12	74.53
Coal	7.40%	38.53	42.99	46.26	46.24	45.12
CCGT	7.40%	96.47	97.23	96.45	91.14	84.34
Nuclear	7.40%	55.99	57.38	58.27	58.90	59.39

Source: Own illustration

6.1.2 Low WACC Case Scenario

In Low WACC Case Scenario when WACC for wind and solar PV are set at 7%, the results are very similar to the base case scenario, except that wind and solar PV levelised costs drop much faster than in the base case. TOC for all technologies in Low WACC case will be the same as in the base case due to the fact that WACC will not affect future TOC. In the Low WACC case, solar PV and CCGT will reach parity as early as 2018, while wind and nuclear will reach parity by 2020. Therefore it can be concluded that as the cost of capital for renewable power projects are dropping, their levelised cost will drop in parallel and they will reach grid parity with other technologies earlier.

Figure 18 LCOE of selected technologies in China low WACC case scenario



Source: Own illustration

Table 22 LCOE of selected technologies in China low WACC case scenario

LCOE selected technologies [USD/MWh]	WACC	2015	2020	2025	2030	2035
Wind	7%	64.19	57.3	53.43	50.94	49.62
PV	7%	114.46	91.69	80.19	73.63	69.35
Coal	7.4%	38.53	42.99	46.26	46.24	45.12
CCGT	7.4%	96.47	97.23	96.45	91.14	84.34
Nuclear	7.4%	55.99	57.38	58.27	58.9	59.39

Source: Own illustration

The effect of changing cost of capital on LCOE of power generation technologies has important implications for policy makers and investors. Until now, most industrial focus has been on the costs of project including among others CAPEX, O&M, supply chain effiency and fuel costs. A lot of effort has been devoted into these tangible cost items in order to lower the cost of generating electricity from these technologies, and indeed substantial progress has been achieved in the past years, especially in the solar PV sector as PV panel costs have been decreasing dramatically. However, not so much has been done to reduce the cost of capital especially for renewables in order to make them competitive compared to conventional energy technologies.

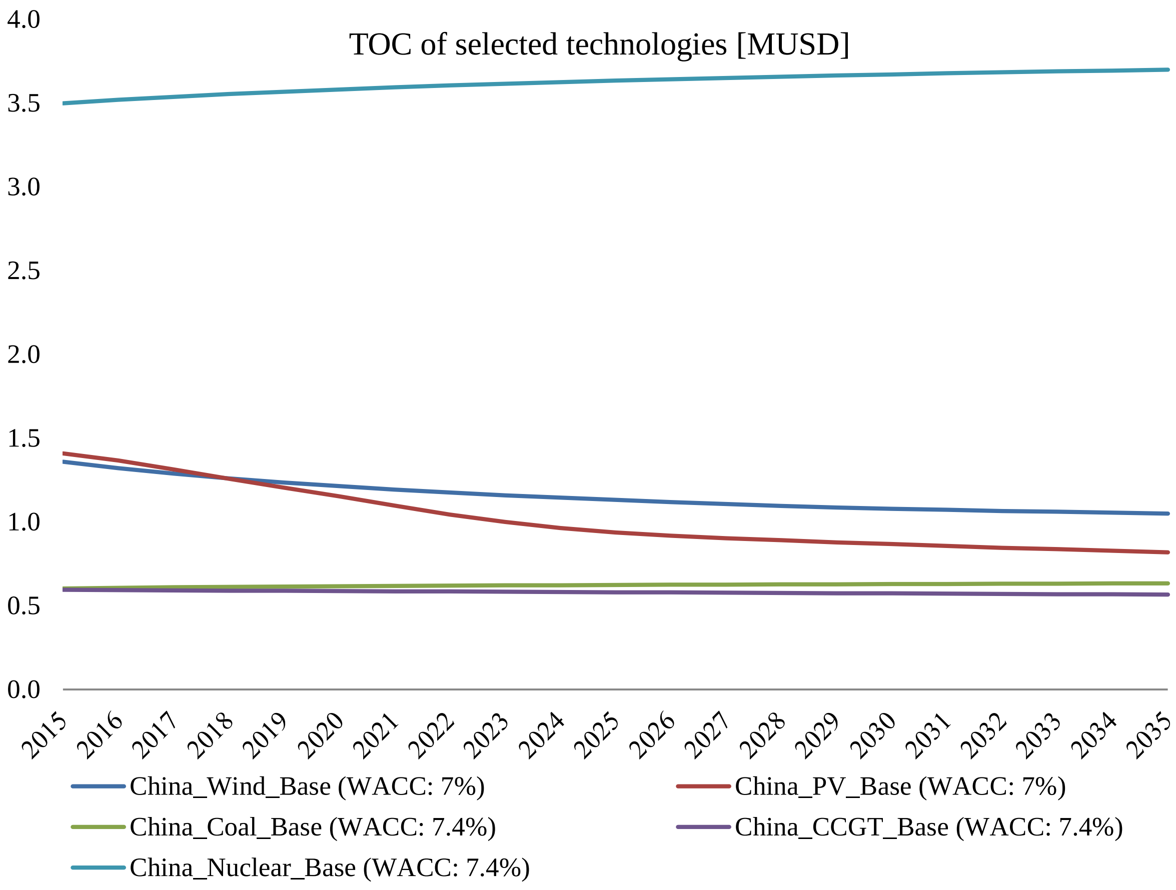
Due to the capital intensive nature of renewable power projects, reducing 1% in cost of capital will bring down LCOE by a significant amount. Cost of capital is directly linked to the perceived risk of each technology. As more and more renewable power projects are deployed globally and overal risk profile reduces, some renewable power projects especially wind and solar PV are being seen as very safe investments. Development and construction risk are almost neglectible. This is what the market in the UK solar PV is currently witnessing, the large influx of capital from pension funds, insurance and Yieldcos that really drive down the cost of capital in the UK solar PV sector.

6.1.3 Current Case Scenario

As we assume constant growth of 18GW of solar PV each year until 2035 in the current case, the local learning rate for solar PV will be different than in the previous two cases. The result is that the TOC for solar PV will drop very slightly slower than in the other two cases. However, we see a very sharp decline in the LCOE of solar PV in this case. LCOE of solar PV will approach closer to wind than in the other two cases.

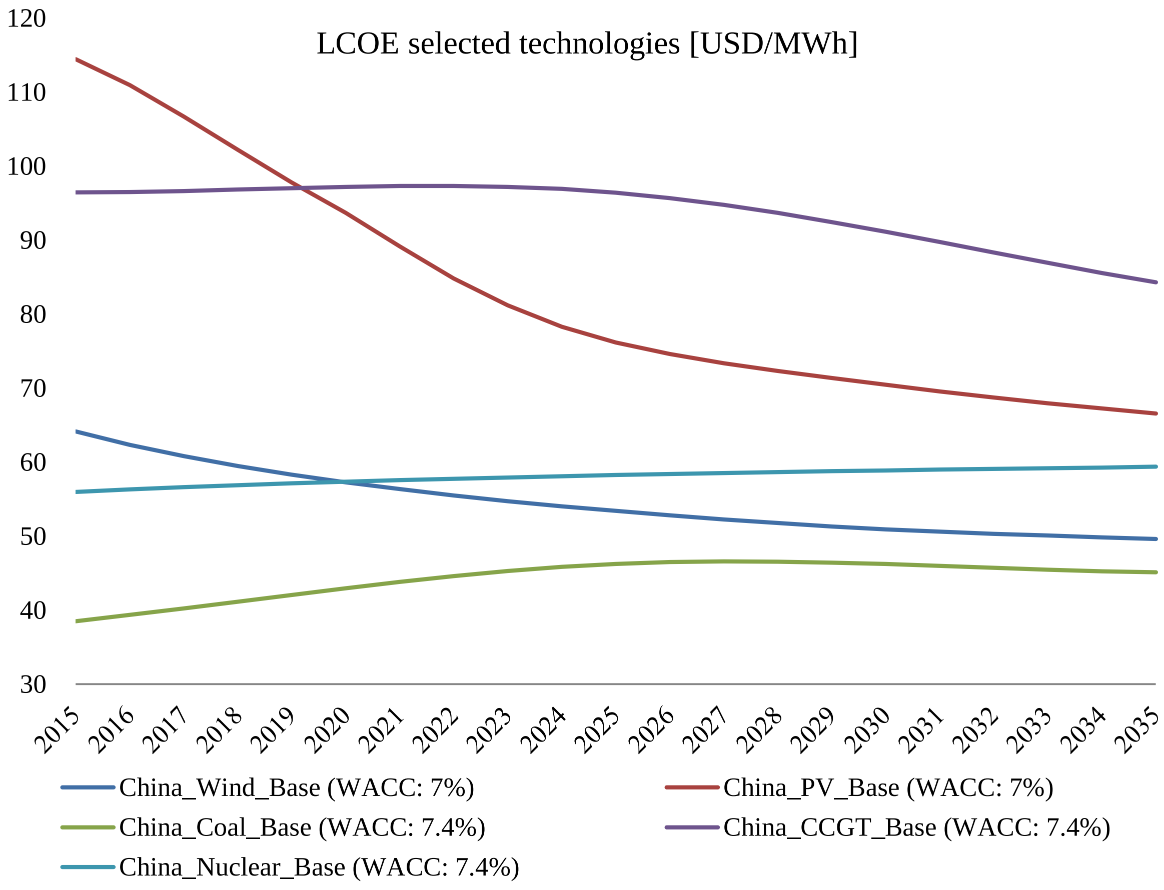
As we assumed constant growth of 18 GW per annual until 2035, the increase in percentage is higher in the early years than later years. Therefore the curve for solar PV LCOE has a steeper slope in the early years and then flattens out as time passes. In this case, it will eventually take more years for solar PV to reach grid parity with wind, nuclear or coal as the installed capacity is increasing at much lower rate and therefore learning effect is diminishing.

Figure 19 TOC of selected technologies in China in current case scenario



Source: Own illustration

Figure 20 LCOE of selected technologies in China current case scenario



Source: Own illustration

Table 23 LCOE of selected technologies in China current case scenario

LCOE selected technologies [USD/MWh]	WACC	2015	2020	2025	2030	2035
Wind	7%	64.19	57.30	53.43	50.94	49.62
PV	7%	114.46	93.70	76.18	70.47	66.59
Coal	7.40%	38.53	42.99	46.26	46.24	45.12
CCGT	7.40%	96.47	97.23	96.45	91.14	84.34
Nuclear	7.40%	55.99	57.38	58.27	58.90	59.39

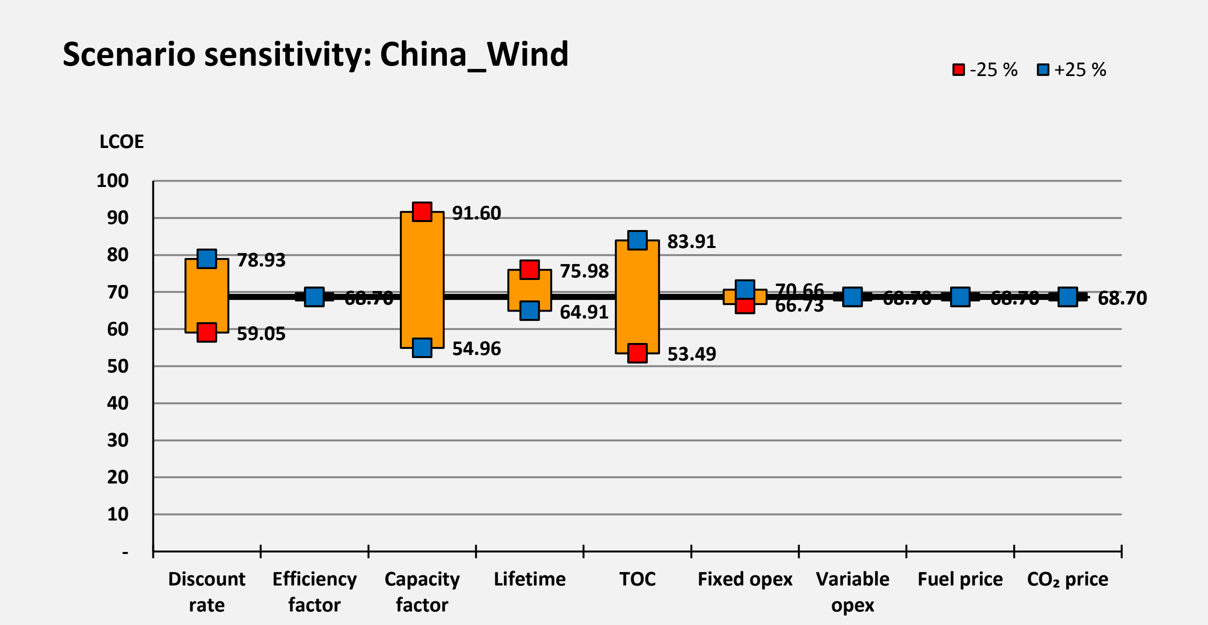
Source: Own illustration

6.2 Sensitivity Analysis

The results from modelling are very dependent on various inputs and assumptions. Therefore it is very important to look at the sensitivity of the result with respect to different variables used in the model in order to understand how changes in certain input will to what extend change the results.

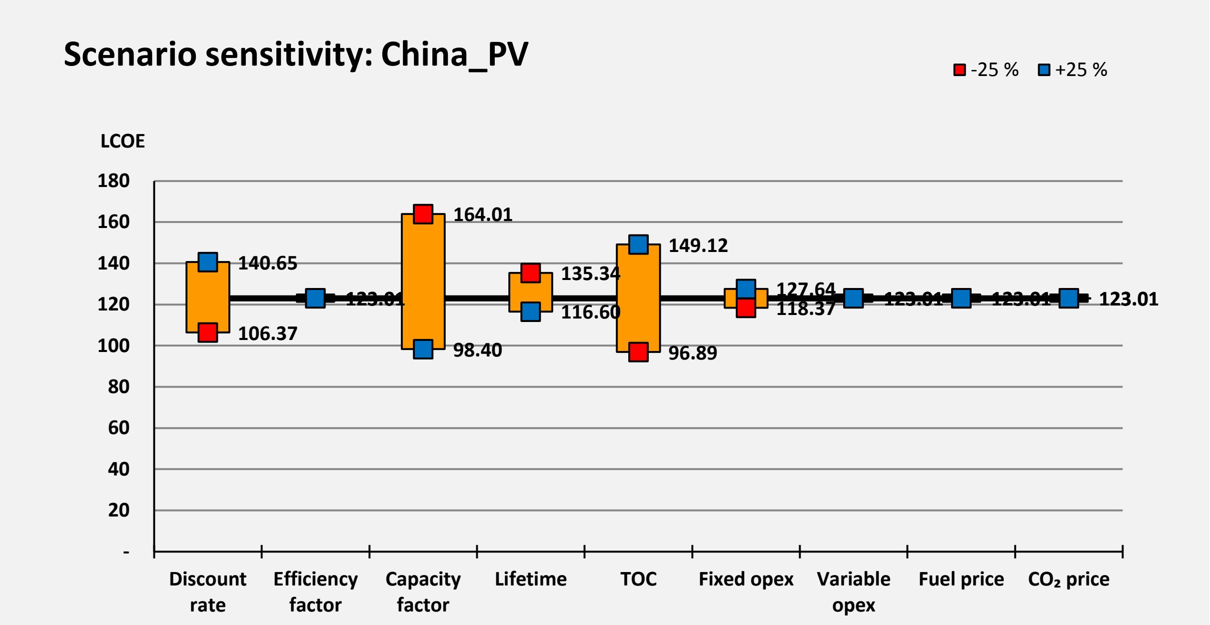
In this study, we apply sensitivity analysis on the following variables: discount rate, efficiency factor, capacity factor, lifetime, TOC, fixed OPEX, variable OPEX and fuel price variations. Sensitivity analysis is performed for each technology based on the base case scenario. We study the change to LCOE given a change of ±5%, ±10%, ±15%, ±20%, ±25% on each variable respectively. The sensitivity analysis results are presented in the following graphs.

Figure 21 Sensitivity analysis wind base case



Source: Own illustration

Figure 22 Sensitivity analysis solar PV base case



Source: Own illustration

The above two figures imply that for solar PV and wind, discount rate, capacity factor, lifetime and TOC all have significant effect on the LCOE results. In particular, capacity factor has the largest effect, followed by TOC, discount rate and then lifetime. Fixed OPEX will also have some minor effect on final LCOE calculation.

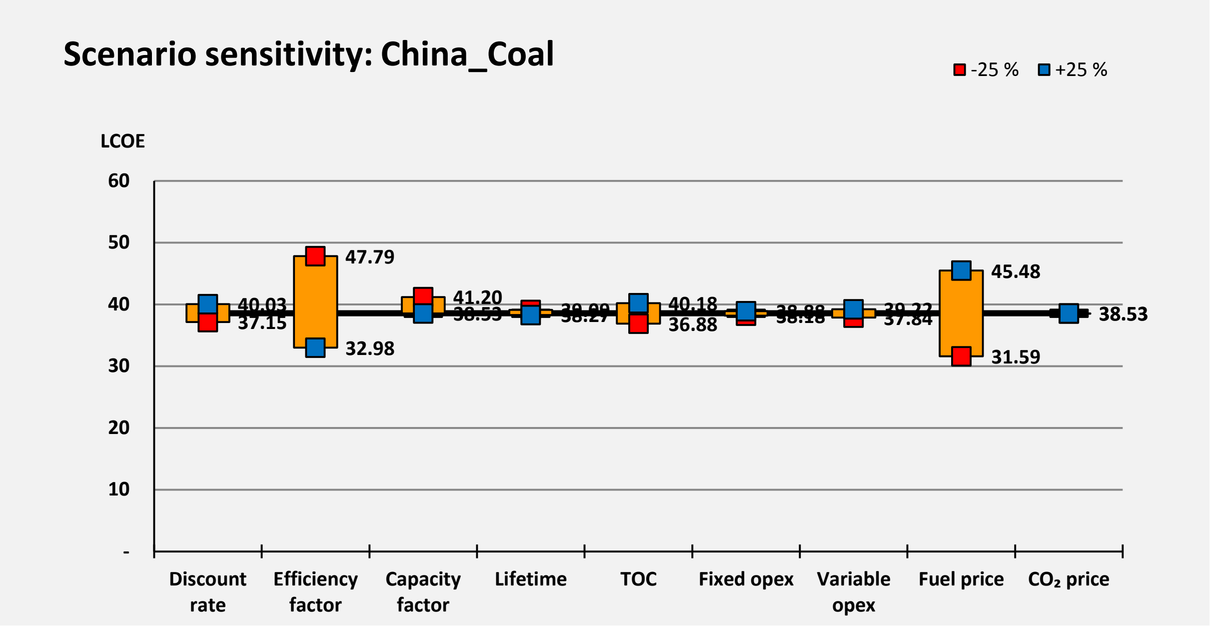
The above results do not seem surprising at all. Both wind and solar PV have much lower capacity factor than thermal power plants because of the nature of their dependence on solar irradiation and wind speed. As there is no marginal cost of production for solar PV and wind, any increase in capacity factor will directly translates into increase in lifetime electricity production and therefore lower LCOE.

With much higher upfront capital costs and therefore interest expenses during loan life than these of thermal power plants, wind and solar PV will also be very much exposed to changes in TOC and discount rate in calculating their LCOEs. This is also true for nuclear power plants as nuclear is also very capital intensive and required large upfront capital expenditure and financing costs comprise the majoring of its ongoing expenses.

It is also worth mentioning that wind and solar PV LCOEs are also prone to lifetime assumptions as shown in figure 15 and figure 16. Lifetime for wind and solar PV are both assumed to be 25 years in our model. For coal fired power plant and CCGT, they are assumed to be 35 and 30 respectively. Lifetime for a nuclear power plant is assumed to be 60 years.

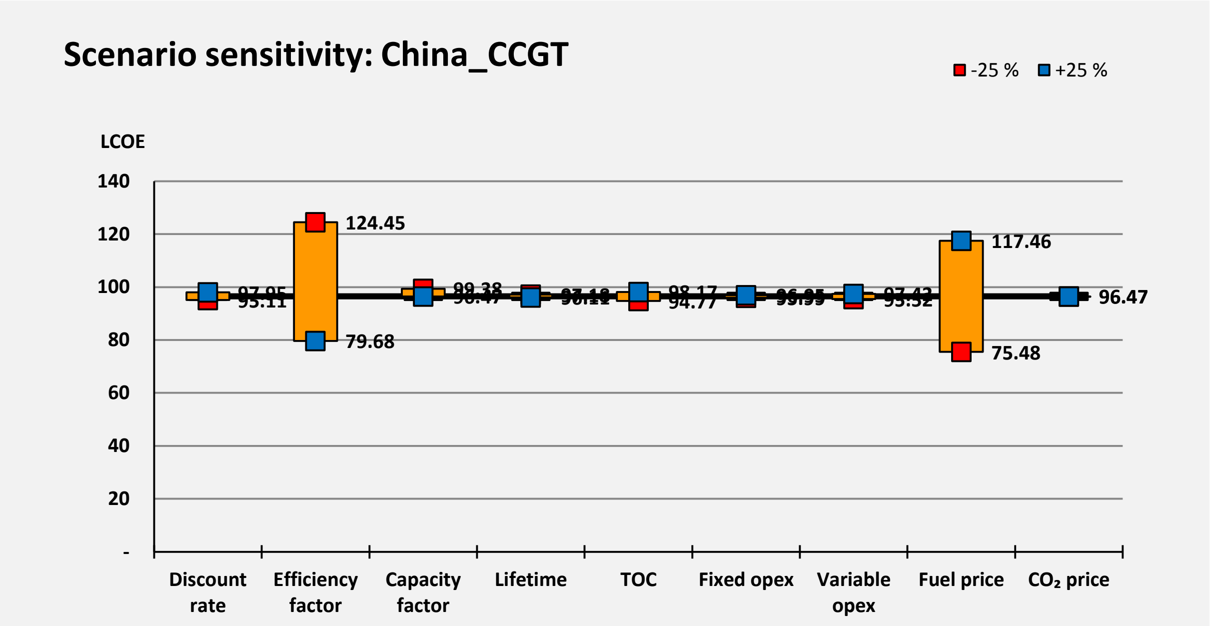
Wind and solar PV have the shortest lifetime and their marginal cost of production is almost zero. Therefore any increase in lifetime will result in higher output and therefore lower LCOE.

Figure 23 Sensitivity analysis coal base case



Source: Own illustration

Figure 24 Sensitivity analysis CCGT base case



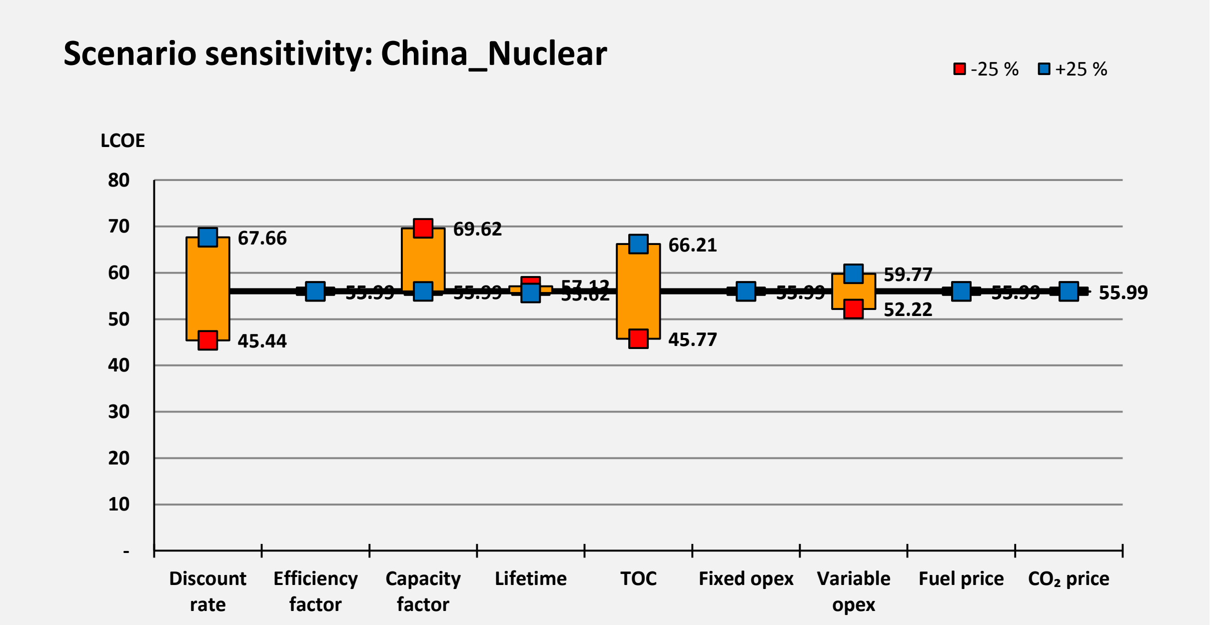
Source: Own illustration

LCOEs for coal fired power plants and CCGT, on the other hand are more sensitivity to changing fuel efficiency factor and fuel prices as shown in the two figures above. They are not much affected by TOC or discount rate as compared to nuclear and renewable power. This is also easy to explain as coal fired power plant and CCGT both require fuel to produce electricity and fuel is one of the major cost components for their LCOE. Therefore changes in coal or gas prices in future will change the LCOE of coal and gas fired plants significantly.

Nuclear power plant also requires fuel to produce electricity. However the cost of uranium is a relatively very small part of the overall costs. According to World Nuclear Association, the fuel costs of a nuclear power plant in the OECD are typically about a third of those for a coal-fired plant and between a quarter and a fifth of those for a gas combined-cycle plant, even after incorporating the associated costs of management of radioactive used fuel and the ultimate disposal of this used fuel or the wastes separated from it.

One component that was not included in the calculation of LCOE and could be significant for nuclear power plants is the decommissioning cost at the end of plant life. Decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant (World Nuclear Association, 2015). However, given that the lifetime of a nuclear power plant is 60 years, that decommissioning costs after discounting back to the current prices, is almost negligible. Therefore we ignored it just as we did for other power generation technologies in our calculation of LCOE.

Figure 25 Sensitivity analysis nuclear base case



Source: Own illustration

6.3 Limitations

Comparing our results under the current case scenario with studies done by other institutions such as NREL, EIA, and Fraunhofer ISE among others, we can conclude that our LCOE calculations are well within the reasonable range, even though these studies were done for different projection year, different countries and under different assumptions as shown in the table below. However, that does not mean in any way that our result is an accurate representation of what will actually happen in reality in future.

Table 24 Comparison of LCOE results of reviewed literature

Name of the Study	Year Conducted	Focus Country	Projection Year	CCGT	Coal-fired	Solar PV	Wind
EUSUSTEL	2007	EU-25	2030	70-73	28-52	44-118	26-89
EPIA	2011	Global	2020	x	x	104	x
NREL	2010	U.S.	2030	53	53	211	56
EWEA	2010	Global	2030	104	136,5	x	71,3
Fraunhofer ISE	2013	Germany	2030	112-162	100-137	61-125	50-125
EIA	2014	U.S.	2040	81,2	87	101,3	73,1
Thesis	2015	China	2030	91.14	46.24	70.47	50.94

Source: various institutions and own illustration

The difficulty with predicting future energy costs using models is that models rely on inputs which are neither one hundred percent accurate nor a perfect representation of future numbers. Besides, no model is perfect. Therefore most studies in the past tried to assess the LCOE for different technologies by formulating various scenarios. As a result, the studies yielded a range that LCOE would most probably lie within in the future. When looking at these numbers and ranges, it is important to bear in mind that the general trend that they represent is more reliable on the actual numbers.

The research presented in this report is no exception. During the construction of the model and choosing inputs for the model, many assumptions and simplifications were made. Below is a brief summary of the assumptions and treatments that might be significant in evaluating the results of the research:

First of all, models always suffer from trade-off between accuracy and flexibility. In order to get more accurate result, a model has to incorporate as much details accurately as possible. The drawback of this approach is that too much details will make the model very complex and technology specific. As we are computing LCOE to compare energy cost across different technologies and different countries, it is important to keep the model flexible enough so that it is applicable to all chosen technologies.

For example, in this research we decided not to break down costs into technology specific costs such as main equipment costs, installation, permitting etc. Instead we grouped them together and used a lump sum cost of Total Overnight Cost which is the sum of all costs associated to build a power plant as if it will be built overnight.

Some other factors that were not included in the model include degradation factor for solar PV and wind, decommissioning costs for all technologies, curtailment, carbon prices, other emission control measures, etc. All these factors could change the results either marginally or substantially. For example, if China is going to impose carbon emission constraint on all power plants, and therefore put a price on carbon emissions, then this will change the cost of electricity generated from coal fired power plants substantially as these plants are the second largest source of carbon emissions in China.

In addition to that, the reliability of the plant data source and sample size need to be scrutinized. As mentioned earlier, operating and financial data on projects were obtained mostly based on Feasibility Study Reports. It was very hard if not impossible to obtain actual cost data due to sensitivity and confidentiality of these statistics. Therefore they are theoretical data that may not be exactly the same as the actual figures. In addition, the sample size is still relatively small and may not be a good representation of a typical power plant. Even within China, there is still very large difference in costs and operational capacities for the same technology due to geographical distribution or local price differentials such as land etc. Therefore these figures only give a rough estimate of what actual costs and operational capacities will be for a Greenfield power plant.

To add to the uncertainty to the results, all the assumptions made such as WACC, local and global learning rates, local and global content breakdown, plant lifetime, fuel prices and price levels could potentially be far from what they are in reality. They are treated to the best knowledge and judgement of the author and team working on other countries other than China. Some of these assumptions, such as WACC as discussed in the sensitivity analysis above, could be material to the final results. Hence the accuracy of these assumptions will also determine how close our results are to the actual costs and development path up to 2035.

The exclusion of taxes from the analysis may have a favourable effect on certain technologies with high capital costs and low operational costs (e.g. renewable technologies). Similarly, the exclusion of tax credits and depreciation incentives may have a relatively favourable effect on conventional technologies compared with renewables.

Last but not least, some inputs such as WACC, efficiency factor, plant lifetime, learning rates, global and local content breakdown etc. were treated as constants throughout the analysed period. However, these could all change as technology advances or investment environment improves. For instance, the cost of capital as represented by WACC has decreased substantially for renewable technologies in the past few years not only in developed countries but also in developing countries that used to be perceived as very risky investment destinations.

In the offshore wind sector, (Dismukes & Upton, 2013), after studying overnight costs of 41 offshore wind farms located in eight different countries worldwide, found out that there was little evidence of economies of scale or learning curves in the offshore wind market. Investing in more offshore wind will not necessarily lead to a decrease in costs of future projects. In fact the results showed that overnight costs had been rising as more offshore wind capacity was deployed, partly because projects were going further and further offshore.

Contrary to the rising overnight costs, offshore market in the UK and other countries in the North Sea and Baltic are attracting not only utilities but many other players who traditional do not invest in offshore wind. Government and other institutions have been talking about the target to decrease the LCOE of offshore wind to below €100/MWh by 2020. However, most of these cost decline has come from the decrease in cost of capital, as more capital flow into the offshore market that drives down the cost of financing these projects.

Therefore some of these assumptions are not static but rather dynamic during the analysed period and this may change the results substantially. However, to make precise predictions on the development path of these factors and retrofit the model is way beyond the scope of this master thesis and would need much further work. As a result this paper will not do any further than the current assumptions on these factors.

7 Conclusion

As part of the broader project commissioned by Statkraft, this particular study is important because China is going to be the price setting country for all five technologies studies except CCGT in future.

China is already supplying the majority of solar PV panels in the global market today. It also deploys the most solar PV projects annually and it is expected to do so in the coming decades.

China is also installing the largest number of wind projects in the world. With its massive excess capacity, continued innovation and quality improvement, it is expected to export more and more onshore wind turbines. Given its impressive dominance of solar PV panels in just limited time, there is a very high chance that China will dominate the world's wind turbine market as well due to its cost competiveness.

Gas fired power technology is expected to remain as a marginal power generation technology in China due to higher LNG prices and therefore higher LCOE. Most of the planned CCGT plants will be deployed in the east part of China to replace coal fired power plants to reduce air pollution. Therefore most gas fired plants will be combined heat and gas plants that will be deployed in the northeast of China.

China is already exporting advanced coal fired technology and equipment to many countries. Given its massive scale of future deployment and the fact that China has developed advanced coal technology with its own intellectual property at much lower costs, China is expected to dominate world's coal fired technology in the decades to come.

Nuclear and high speed train are the two pillars of Chinese high end machinery export that is being one of the highest priority for the state. China has the largest pipeline of nuclear power plants in construction and it has developed its own nuclear technology. With the engineering experience, human capital and financing from Chinese banks, China will export and be the dominant player in the global nuclear market as well.

Modelling results show that coal will continue to be the cheapest form of generation up to 2035 without taking into consideration of carbon prices. Nuclear is the second cheapest for of energy right now, but is expected to be surpassed by onshore wind very soon. Solar PV will see the largest decline of cost approaching 2035, though it will still be higher than that of wind, nuclear and coal. CCGT will be the most expensive form of energy in 2035, largely due to higher capital costs and higher LNG prices in Asia.

The results are in line with most other studies, though the predicted range is usually quite wide in these studies. They are also in line with current Chinese energy policies. China is promoting cheap renewables such as wind and solar in an unprecedented scale. However, it is still developing advanced coal fired power technology and nuclear to meet future energy demand and reduce carbon emissions. However, it does not have an ambitious plan to build more gas fired power plants due to its much higher costs of energy.

Due to limitations of the model, inputs, accuracy of data etc, the modeling results should not be treated as an exact prediction of future cost development trajectory. Instead the overall trend is more important than the exact numbers.

Given the limitations, further research opportunities lie in the more comprehensive treatment of modelling assumptions and inputs. For instance, the static assumptions of capacity factor, WACC, learning rates, global and local contents etc could all vary as time passes.

Other cost items such as taxes, depreciation, subsidies etc could also be factored into the model to derive a more realistic cost prediction of these power generation technologies.

8 Bibliography

BCG. (2013). *BCG Classics Revisited: The Experience Curve.*

Chen, K. (2014). Upgrading of Coal Fired Power Technologies. http://www.csee.org.cn/data/zt_qjrm2014/ppt/ks1.pdf.

Deutsche Bank. (2015). *2015 Solar Outlook.*

Dismukes, D., & Upton, G. (2013). Economies of Scale, Learning Curves and Offshore Wind Development Costs.

Energy Information Administration (EIA). (2013). *Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants.* Abgerufen am 2015 von http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf

Fraunhofer Institute for Solar Energy Systems ISE. (2013). *Levelized Cost of Electricity Renewable Energy Technologies .*

International Atomic Energy Agency. (2014). *International Status and Prospects for Nuclear Power 2014.*

International Energy Agency (IEA). (2014). *Technology Roadmap - Solar Photovoltaic Energy 2014 edition.*

International Energy Agency, OECD Nuclear Energy Agency. (2010). *Projected Costs of Generating Electricity.*

IRENA. (2015). *Renewable Power Generation Costs in 2014.*

National Bank of Abu Dhabi . (2015). *Financing the Future Energy.*

Sun, G. (2010). *Coal in China: Resources, Uses, and Advanced Coal Technologies.*

Sung, M. (2014). Integrated Gasification Combine Cycle (IGCC) Technologies. Von http://www.csee.org.cn/data/zt_qjrm2014/ppt/ks4.pdf abgerufen

World Nuclear Association. (2015). *The Economics of Nuclear Power*. Von http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/ abgerufen

World Nuclear Association. (2015). *The Economics of Nuclear Power*.

Bhandari, R., & Stadler, I. (2009). Grid parity analysis of solar photovoltaic systems in Germany using experience curves. *Solar Energy, 83*(9), 1634-1644. doi:10.1016/j.solener.2009.06.001

de la Tour, A., Glachant, M., & Meniere, Y. (2013). Predicting the costs of photovoltaic solar modules in 2020 using experience curve models. *Energy, 62*, 341-348. doi:10.1016/j.energy.2013.09.037

Ek, K., & Soderholm, P. (2010). Technology learning in the presence of public R&D: The case of European wind power. *Ecological Economics, 69*(12), 2356-2362. doi:10.1016/j.ecolecon.2010.07.002

Ferioli, F., Schoots, K., & van der Zwaan, B. C. C. (2009). Use and limitations of learning curves for energy technology policy: A component-learning hypothesis. *Energy Policy, 37*(7), 2525-2535. doi:10.1016/j.enpol.2008.10.043

IRENA. (2015). *RENEWABLE POWER GENERATION COSTS IN 2014* Retrieved from

ISE, F.-I. f. S. E. S. (2015). *Current and Future Cost of Photovoltaics* Retrieved from

Kahouli-Brahmi, S. (2009). Testing for the presence of some features of increasing returns to adoption factors in energy system dynamics: An analysis via the learning curve approach. *Ecological Economics, 68*(4), 1195-1212. doi:10.1016/j.ecolecon.2008.08.013

Kiss, B., & Neij, L. (2011). The importance of learning when supporting emergent technologies for energy efficiency-A case study on policy intervention for learning for the development of energy efficient windows in Sweden. *Energy Policy, 39*(10), 6514-6524. doi:10.1016/j.enpol.2011.07.053

Kobos, P. H., Erickson, J. D., & Drennen, T. E. (2006). Technological learning and renewable energy costs: implications for US renewable energy policy. *Energy Policy, 34*(13), 1645-1658. doi:10.1016/j.enpol.2004.12.008

Neij, L. (1999). Cost dynamics of wind power. *Energy, 24*(5), 375-389. doi:10.1016/s0360-5442(99)00010-9

Neij, L. (2008). Cost development of future technologies for power generation - A study based on experience curves and complementary bottom-up assessments. *Energy Policy, 36*(6), 2200-2211. doi:10.1016/j.enpol.2008.02.029

Ouyang, X., & Lin, B. (2014). Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. *Energy Policy, 70*, 64-73. doi:10.1016/j.enpol.2014.03.030

Rubin, E. S., Yeh, S., Antes, M., Berkenpas, M., & Davison, J. (2007). Use of experience curves to estimate the future cost of power plants with CO2 capture. *International Journal of Greenhouse Gas Control, 1*(2), 188-197. doi:10.1016/s1750-5836(07)00016-3

Tidball, R., Bluestein, J., Rodriguez, N., & Knoke, S. (2010). *Cost and Performance Assumptions for Modeling Electricity Generation Technologies*. Retrieved from

Yuan, J. H., Sun, S. H., Zhang, W. H., & Xiong, M. P. (2014). The economy of distributed PV in China. *Energy*, *78*, 939-949. doi:10.1016/j.energy.2014.10.091

9 Appendices

Appendix 1 Chinese Wind Turbine Market

Ranking	Name	Installed Capacity MW 2014	Installed Capacity 2013	Installed Capacity 2012	Market Share % in 2014	Market Share % in 2013	Market Share % in 2012
1	Goldwind	4,434	3,750	2,521	18.99%	23.31%	19.50%
2	United Power	2,600	1,487	2,029	11.14%	9.25%	15.70%
3	Ming Yang	2,058	1,286	1,133	8.81%	7.99%	8.70%
4	Envision Energy	1,963	1,128	544	8.40%	7.01%	4.20%
5	XEMC	1,781	1,052	893	7.63%	6.54%	6.90%
6	Shanghai Electric	1,744	1,014	822	7.47%	6.30%	6.30%
7	Dongfang	1,298	573	466	5.56%	3.56%	3.60%
8	CSIC HZ Wind Power	1,144	786	399	4.90%	4.89%	3.10%
9	Windey	898	538	364	3.85%	3.35%	2.80%
10	Sinovel	789	896	1,203	3.38%	5.57%	9.30%
-	Foreign Suppliers	359	937	967	1.77%	5.86%	7.50%

Appendix 2 Chinese Wind Turbine Export in 2013

SN	Supplier	Country	No	Installed Capacity MW	Share %
1	Goldwind	Australia	73	165.5	52.18
		Pakistan	33	49.5	
		Panama	22	55	
		Bolivia	2	3	
		Romina	20	50	
		Turkey	7	5.25	
		Chile	22	33	
		Subtotal	179	361.25	
2	Sinovel	South Africa	18	54	20.37
		Sweden	10	30	
		Turkey	12	18	
		Italy	13	39	
		Subtotal	53	141	
3	SANY	Ethiopia	56	84	13.29
		USA	4	8	
		Subtotal	60	92	
4	Swisselectric	Cyprus	10	20	9.97
		Thailand	3	9	
		Iran	20	40	
		Subtotal	33	69	
5	Ming Yang	India	7	10.5	1.52
6	Envision Energy	Chile	5	10.5	2.04
		Denmak	1	3.6	
		Subtotal	6	14.1	
7	Dongfang	Finland	3	4.5	0.65
Total			341	692.35	100

Appendix 3 Cumulative Wind Turbin Export by 2013

SN	Country	No	Installed Capacity MW	Share %
1	USA	186	335.75	24.11
2	Australia	86	185	13.29
3	Ethiopia	90	135	9.69
4	Italy	35	91.5	6.57
5	Turkey	55	77.25	5.55
6	Panama	22	55	3.95
7	South Africa	18	54	3.88
8	Bulgaria	34	51.5	3.7
9	Romina	20	50	3.59
10	Pakistan	33	49.5	3.55
11	Chile	32	48.84	3.51
12	Iran	23	45.5	3.27
13	Sweden	12	36	2.59
14	Spain	12	36	2.59
15	Brazil	23	34.5	2.48
16	India	17	25.5	1.83
17	Thailand	10	22	1.58
18	Cyprus	10	20	1.44
19	Ecuador	11	16.5	1.18
20	Finland	3	4.5	0.32
21	Cuba	6	4.5	0.32
22	UK	3	3.75	0.27
23	Denmark	1	3.6	0.26
24	Bolivia	2	3	0.22
25	Kazakhstan	2	1.56	0.11
26	Belarus	1	1.5	0.11
27	Uzbekistan	1	0.75	0.05
Total	748	1392.5	100	

Appendix 4 World's Top 10 Solar Panel Markers 2014

Ranking	Name	Ranking change from 2013	Country
1	Trina Solar	+1	China
2	Yingli Green Energy	-1	China
3	Canadian Solar	0	China/Canada
4	Jinko Solar	+1	China
5	JA Solar	+4	China
6	Sharp Solar	-2	Japan
7	Renesola	-1	China
8	First Solar	-1	USA
9	Hanwha SolarOne	-1	China
10	SunPower	+1	USA
10	Kyocera	0	Japan

Appendix 5 China's Top 10 Solar EPC 2013

Ranking	Name	Ranking in 2012	Country
1	TEBA	2	China
2	GD Solar	1	China
3	Zhenhua New Energy	3	China
4	Yingli Solar	7	China
5	Astronergy	4	China
6	Rays Power	8	China
7	China Power Construction Group	5	China
8	HT-SAAE	6	USA
9	China Wind Power Group	9	China
10	Jinko Solar	12	China

Appendix 6 Historical Installed Capacity and Share

Year	Total	Hydro		Coal	
		Capacity MW	Share %	Capacity MW	Share%
1949	1,849	163	8.8	1,686	91.2
1952	1,964	190	9.6	1,780	90.4
1957	4,640	1,020	22.0	3,620	78.0
1962	13,040	2,380	18.3	10,660	81.7
1965	15,080	3,020	20.0	12,060	80.0
1970	23,770	6,240	26.3	17,530	73.7
1975	43,410	13,430	30.9	29,980	69.1
1978	57,120	17,280	30.3	39,840	69.7
1979	63,020	19,110	30.3	43,910	69.7
1980	65,870	20,320	30.8	45,550	69.2
1981	69,130	21,930	31.7	47,200	68.3
1982	72,360	22,960	31.7	49,400	68.3
1983	76,440	24,160	31.6	52,280	68.4
1984	80,120	25,600	32.0	54,520	68.0
1985	87,050	26,410	30.3	60,640	69.7
1986	93,820	27,540	29.4	66,280	70.6
1987	102,900	30,190	29.3	72,710	70.7
1988	115,500	32,700	28.3	82,800	71.7
1989	126,640	34,580	27.3	92,060	72.7
1990	137,890	36,050	26.1	101,840	73.9
1991	151,470	37,880	25.0	113,590	75.0
1992	166,530	40,680	24.4	125,850	75.6
1993	182,910	44,890	24.5	138,020	75.5
1994	199,900	49,060	24.5	148,740	74.4
1995	217,220	52,180	24.0	162,940	75.0

Year	Total	Hydro		Coal	
		Capacity MW	Share %	Capacity MW	Share%
1996	236,540	55,580	23.5	178,860	75.6
1997	254,240	59,730	23.5	192,410	75.7
1998	277,290	65,070	23.5	209,880	75.7
1999	298,770	72,970	24.4	223,430	74.8
2000	319,320	79,350	24.8	237,540	74.4
2001	338,490	83,010	24.5	253,140	74.8
2002	356,570	86,070	24.1	265,550	74.5
2003	391,410	94,900	24.2	289,770	74.0
2004	442,390	105,240	23.8	329,480	74.5
2005	517,180	117,390	22.7	391,380	75.7
2006	623,700	130,290	20.9	483,820	77.6
2007	718,220	148,230	20.6	556,070	77.4
2008	792,731	172,604	21.8	602,858	76.1
2009	874,097	196,290	22.5	651,076	74.5
2010	966,413	216,057	22.4	709,672	73.4
2011	1,062,532	232,979	21.9	768,340	72.3
2012	1,146,764	249,470	21.8	819,682	71.5
2013	1,257,676	280,441	22.3	870,091	69.2

Appendix 7 Cost breakdown of a typical coal fired power plant in China

Name	Construction	Equipment	Installation	Others	Sum 2014 RMB '0000	Sum 2015 M$/MW	% of OCC
Main and Auxiliary	**72,429**	**249,044**	**82,876**		**404,349**	**0.50**	**83.82**
Heating System	22,583	161,080	47,488		231,151	0.29	47.92
Fuel Supply System	7,039	4,809	411		12,259	0.02	2.54
Ash Disposal System	1,795	5,537	1,285		8,617	0.01	1.79
Water Treatment System	1,137	2,609	1,355		5,101	0.01	1.06
Water Supply System	20,803	23,970	4,666		49,439	0.06	10.25
Electric System	2,387	25,827	12,850		41,064	0.05	8.51
Heat Control		6,496	6,207		12,703	0.02	2.63
SO Disposal	2,077	8,351	5,684		16,112	0.02	3.34
NO Disposal	309	7,787	1,998		10,094	0.01	2.09
Auxiliary	14,299	2,577	932		17,808	0.02	3.69
Factory Related	**14,273**	**6,583**	**3,650**		**24,506**	**0.03**	**5.08**
Transport System	5,225	6,400	420		12,045	0.01	2.5
Ash deposit etc	3,506	183	123		3,812	0.00	0.79
Water supply	432				432	0.00	0.09
Plant Site	2,735				2,735	0.00	0.57
Factory Construction	1,173				1,173	0.00	0.24
Other temporary system	1,202				1,202	0.00	0.25
Water supply			3,108		3,108	0.00	0.64
Cost differential in construction period	909		2,933		3,842	0.00	0.8
Other Costs				**30,549**	**30,549**	**0.04**	**6.33**
Land and Site development				5,684	5,684	0.01	1.18
Construction Management Fee				9,520	9,520	0.01	1.97

Technical Service Fee				10,573	10,573	0.01	2.19
System Start-up fee				743	743	0.00	0.15
Production prep fee				3,730	3,730	0.00	0.77
Transportation				300	300	0.00	0.06
Contingencies	**4,335**	**12,781**	**4,326**	**1,527**	**22,969**	**0.03**	**4.76**
OCC	**91,037**	**268,408**	**90,852**	**32,076**	**482,373**	**0.60**	**100**
IDC				29,344	29,344	0.04	6.08
Total Investment	**91,037**	**268,408**	**90,852**	**61,420**	**511,717**	**0.63**	106.08
VAT Deductible		36,713			36,713	0.05	7.61
Start-up cash flow				2,989	2,989	0.00	0.62
Project Total Cash Outlay	**91,037**	**268,408**	**90,852**	**64,409**	**514,706**	**0.64**	106.70