KTH Royal Institute of Technology

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Thesis on the

The Electricity Model for China – Insights and Implications of Energy Policies

by

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The Electricity Model for China – Insights and Implications of Energy Policies

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Abstract

China remains one of the largest producer and consumer of energy in the world. An understanding of the complex nature of the energy resources in this country is of a high interest due its impacts on global scale. In this Thesis, the electricity supply system of China is modelled using the medium to long-term open source energy modelling system tool OSeMOSYS. Three scenarios are developed and analysed. A Reference scenario that incorporates into the model the country´s current energy policies and targets. A Renewable energy scenario that represents the reaction of the energy system based on an ambitious penetration of renewable energy technologies as well as a Climate change scenario. The latter one, provides an assessment of the electricity sector based on the emission limit set to achieve under the Paris Agreement "below 2 degrees climate goals". Finally, comparison is made between all three scenarios and results show that the energy policies and the current ambitious penetration of renewable energy technologies are not sufficient in meeting the climate change goals in the short term.

Sammanfattning

Kina är fortfarande en av världens största tillverkare och konsument av energi. En förståelse för den komplexa naturen i energiresurserna i detta land är av stort intresse på grund av dess inverkan på en global skala. I denna uppsats modelleras elförsörjningssystemet i Kina med hjälp av det medellånga till långsiktiga energikodningssystemet OSeMOSYS med öppen källkod. Tre scenarier utvecklas och analyseras. Ett referensscenario som inkorporerar modellen i landets nuvarande energipolicy och mål. Ett förnybart energiscenario som representerar energisystemets reaktion baserat på en ambitiös expansion av förnybar energiteknik samt ett klimatförändringsscenario. Den senare ger en bedömning av elsektorn baserat på den utsläppsgräns som ska uppnås enligt Parisavtalet "under 2 graders klimatmål". Slutligen görs en jämförelse mellan alla tre scenarierna och resultaten visar att energipolitiken och den nuvarande ambitiösa expansionen av förnybar energiteknik inte är tillräckligt för att uppfylla klimatmålen på kort sikt.

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1. Introduction

The People´s of Republic of China established in 1949 with a population of above 540 million people. In the same year, the installed capacity for electricity generation was almost 1.85 GW. However, the upcoming decades, the power generation capacity increased to 50 GW in 1982 and to 138 GW in 1990. Electricity is very important for the socio-economic development of a country [1].

China has a population of more than 1.4 billion people, equivalent to 18.7% of the total world's population and a total land area of approximately 9.39 million squared kilometres [2]. The country's Gross Domestic Product (GDP) in 2016 was 11.2 trillion US dollars [3]. China ranked as number one on the list of countries with the largest energy consumption, overtaking the United States in the year 2009 [4]. In addition, China is the country with world's largest power system having an electricity generation capacity above 1000 GW as indicated in 2011, overtaking the United States [1].

China's total energy consumption reached about 3123 million tonnes of oil equivalent (Mtoe) in 2016 [4]. This accounted for 23% and 27% of the world's energy consumption and growth in global energy consumption respectively, also overtaking the United states to achieve the top place as the largest consumers of renewables in power in the year 2016 [5].

Regardless of the high penetration of renewables, China's electricity sector is still dominated by coal power generation. In 2016, coal generation accounted for approximately 64% of the total electricity generation of 3906 TWh. Electricity generation from renewables such as Hydro, Solar, Wind and Pumped Storage amounted to a total of 1488 TWh (25%), and the rest came from other sources such as Nuclear, Gas-fired and other thermal plants [6]. It could be noted down that China has to put in more efforts in order to achieve decarbonisation and sustainable development targets [7].

China has set aspiring climate change goals aimed at achieving carbon (CO_2) emission reduction of 40% – 45% by the year 2020 compared to 2005 levels. In addition, the country also aims to achieve a 15% of total energy consumption from non-fossil energy sources in the same year [8]. China's has also set targets according to the 13th five year plan, to decrease energy consumption and CO_2 per unit of GDP by 15% and 18% respectively by 2020 compared to 2015 levels [9]. Those goals are highly dependent on limiting electricity demand rather than technological developments [8].

Comprehending the connection between energy (electricity), social and economic development goals are crucial for long-term strategic planning. Nevertheless, finding this connection is tedious knowing the existence of fundamental behavioural and structural instruments, especially technology, market advancement, and sustainable development [10].

In this thesis, the electricity supply model of China is modelled and scenarios investigated related to the country´s policies and targets, the penetration of renewables and climate change goals. The analysis will provide outcomes related to power generation requirements, financial requirements, and carbon dioxide emissions.

This analysis, was conducted using the open source for medium to long-term energy planning tool OSeMOSYS and its interface MoManI. In this analysis, the techno-economic parameters of China´s electricity supply system, electricity demands, structure of the electricity system, potential of energy resources, electricity generation mix, and projected plans for electricity are acquired and used to develop the model.

2. Overview

This section will present an overview of China's primary energy supply, transformation and consumption, with a focus on the electricity supply system, and plans and policies.

2.1 Primary Energy Supply and Consumption

China's total primary total primary energy supply amounted to about 4360 Metric Tons Carbon Equivalent (Mtce) in 2016. Coal constituted around 65% of the country´s total energy supply, followed by oil 21%, and natural gas 6% [11]. Regardless of the significant growth in renewable energy resources, China is still far from meeting its energy system transition goals of being efficient and sustainable.

China's industrial sector is the highest energy - consuming sector though all other sectors have also increased their share of energy consumption in recent years. In 2016, the total final energy consumption was approximately 3,230 Mtce where 61% accounted for energy consumed by the industrial sector, 21% from the transport sector, and buildings accounted for 14%. Coal also remains the dominant energy resource used in the end-use sector, and represented 40% of the total final consumption in the year 2016 (Figure 1). The figure below

shows a detailed breakdown by fuel of the country's total final energy supply and consumption for the year 2016 [11].
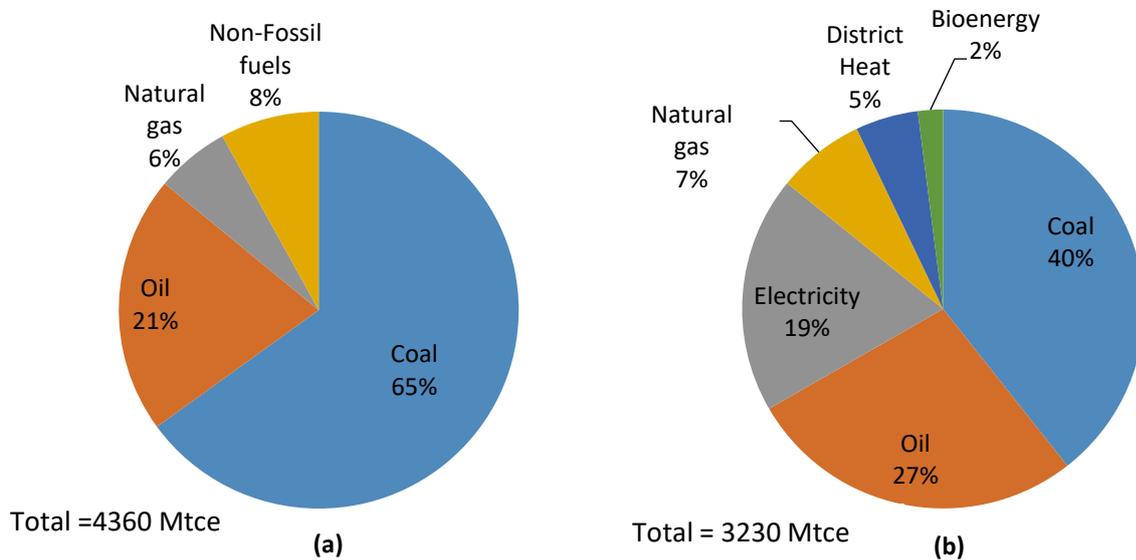
Figure 1: (a) Energy Resources – Supply 2016, (b) Energy Resources – Consumption 2016

2.2 China's Electricity Supply System

China is fully electrified (100% electricity access) [12]. However, one of the country's major challenges is the overcapacity dilemma of which majority of the installed electrical capacity come from fossil fuel resources such as coal [13]. This is mainly due to the investments in coal power plants in the early 2000s and the relatively low increase of the domestic electricity demand since 2013, mainly due to the decreased energy intensity within the industrial sector and a downturn in the economy. To this end, regulators have been propelled to consider a two year freeze period which will halt the approval of new coal –fired power project in the 13th five year plan (FYP). China also remains a major player in the international coal markets and the reformation of its coal sector plays a significant role in the global energy outlook [14] [15].

In 2016, the installed generation capacity was 1625 GW in with an energy mix of 58% from coal generation, 20% hydro, 9% wind, Solar PV 5%, 4% gas, 2% nuclear, 1% oil, and only 1% coming from bioenergy (see figure 2). However, it has been projected that the increase in energy demand in China will be met by renewables and natural gas while demand for coal decreases [15].

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The country´s energy demand will decrease approximately by 1% annually (New policy scenario, IEA) by 2040. This is as a result of several factors including the structural changes in the economy, rigid energy efficiency policies and demographic reforms [15].
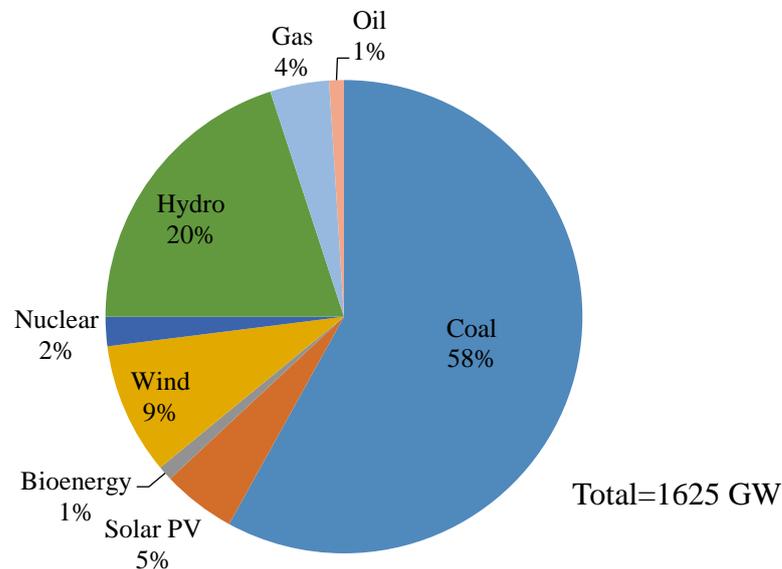
Figure 2: Installed Capacity for Year 2016

Nowadays, about 15% of power generation from wind and solar PV is being curtailed due to the inability of the existing power system to accommodate such excessive and intermittent power. An energy outlook by the International Energy Agency suggests the establishments of heavy funding on new power transmission lines which will enable inland renewable energy potential to be exploited and thus provide electricity to the customers at a lower price closer to the coast. IEA also projects by the year 2030 that China will overtake the United States and European Union to become the top leader in electricity generation from nuclear resources. Gas-fired capacity will triple but only contribute to a 10% share of the total electricity generation in 2030 [15].

Electricity consumption increased to a total of 5920 TWh at the end of 2016. The service sector is the main consumer of the domestic electricity, constituting around 78%. The total electricity consumption over the recent years shows a slow incremental trend with only 5% increase between the 2015 and 2016 compared to the 12% growth between 2010 and 2011. Although there is a relationship between energy consumption and economic growth in China, in the recent time there has been a growing deviation between these two factors as a result of

the implementation of energy efficiency measures, especially within the energy intensive industries [16].

2.3 Energy Plans and Policies

China´s progress on tackling climate change can be justified by their participation and active commitment to the Paris agreement under the United Nations Framework Convention on Climate Change, Conference of Parties (COP) 21 in 2015. Before the COP21 engagement, China had also submitted their Intended Nationally Determined Contributions (INDC) as announced in their new 13th five year plan (FYP) which involves a substantial number of new strategies to be implemented to achieve carbon mitigation targets within from 2016 to 2020 [17].

One of the objectives of the 13th FYP is the development of green initiatives. The plan establishes the government's commitments in solving its extreme environmental degradation and grows its clean energy penetration, green environmental and manufacturing services sector. Ten of the twenty-five targets given in the plan focus on the environment, and are all binding targets that must be met by 2020. These targets propose ambitious objectives to enhance city air quality, reduce carbon dioxide intensity, soil and water contamination, and sets caps on energy use [18]. Based on recent trends, green technologies such as new energy vehicles and green building materials may become the influencing factors for the fastest growing market both in China and for foreign investors [19].

In addition, the 13th FYP introduces targets on energy and CO2 emissions. It includes the first ever national cap of five billion tons of coal on all energy sources over the period 2016 -2020. This cap is aimed at improving energy efficiency, lowering emission, and aiding the transition to a lower energy intensive service sector. These targets have been perceived by both Chinese and international experts as easily achievable and they will set China on the way to fulfilling its commitment towards achieving a peak in carbon emissions in 2030 (Paris Agreement, 2016) [18].

To meet the targets related to energy and emissions in the 13th FYP, the government will need to increase the utilization of clean energy technologies from the 12% stated in the 12th FYP for 2015 to 15% by 2020. The 13th FYP for renewable energy includes a total investment of $373.1 billion for newly installed renewable energy capacity. Newly installed hydropower

will account for 20% of the total investment, 28% for wind, 40% for solar, and the rest allocated to the development of biomass, biogas, power generation and geothermal use [18].

China, under the 13th FYP, aims to achieve a target of 1943 GW in electricity generation capacity in the year 2020, more than 20% increase from the capacity in 2016. The power generation mix in 2020 will be constituted by coal-fired power plants (1100 GW), natural gas power plants (110 GW), nuclear (58 GW) and renewable technologies such as solar (110 GW), wind (210 GW), hydro (340 GW) [16] and Biomass-fired (15 GW) [20].

3. Methodology

In this study the electricity supply system of China developed using the open source energy modelling system tool (OSeMOSYS), a linear cost optimization tool. OSeMOSYS tools help to produce optimized solutions that satisfy given energy demands throughout the defined by the user modelling period. Construction of the model follows the steps shown in figure 3 where the required techno-economic data are inserted to their corresponding blocks [21, 22].

The model outcomes can be used to develop insights on given production technology mix, fuel resources and other parameters for the analysis of the overall energy system. An advantage of the model is that it is an open-source tool with a quick learning curve that allows free accessibility to students, researchers, analysts and individuals or corporate entities working on projects related to energy modelling [22, 21].
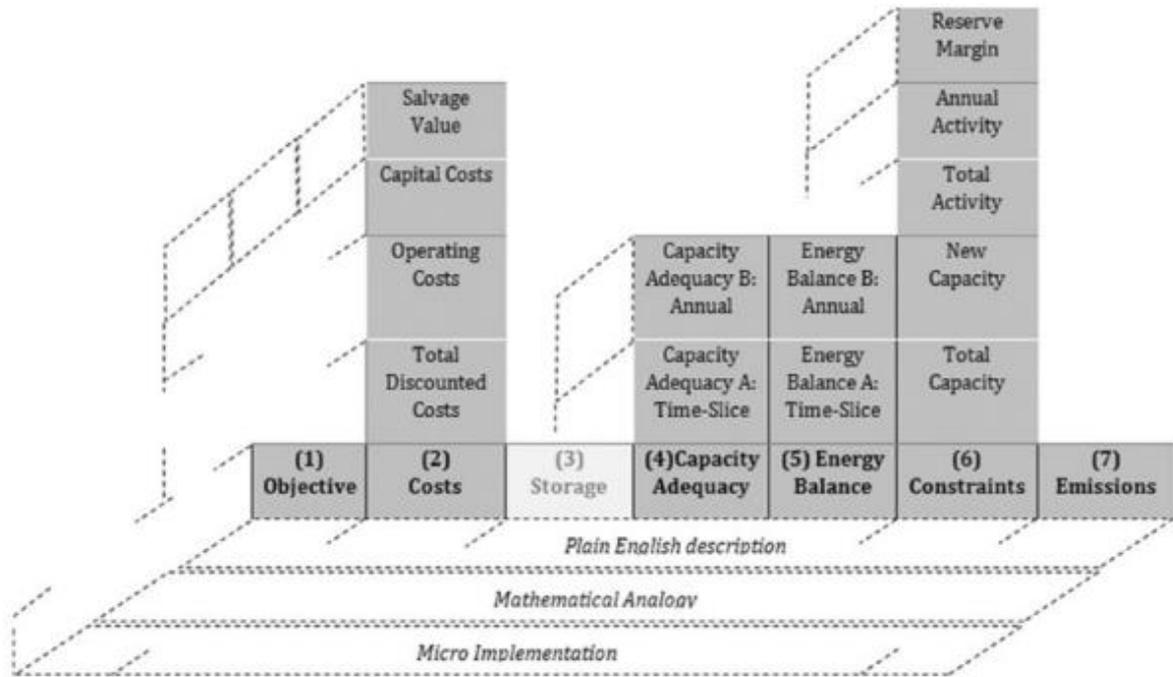
Figure 3: Levels of abstraction in OSeMOSYS

3.1 Model Structure

This model produces a projection using a least cost assessment on China's electricity supply system. In the development of the electricity model base for China, several parameters with their corresponding data are collected. These data are sorted to their respective segments of the electricity generation chain consisting of energy resource input (typically, fuel imports and local fuel extraction), generation technologies (e.g., hydro, coal power plants, etc.), and output electricity to serve the various demand sectors (Industry, Residential, Transport, Services and Others).

The time representation in this model is monthly. This categorises both the energy demand and optimized electricity generation from the combination of technologies needed to satisfy the demand to every month of the year. Model utilizes a twelve segment year split based on the energy consumption in every month of the year [23].

The time period of the model is 2016 – 2040. The model period is selected based on the current energy plans for 2020 as well as taken into account future demand projections and policies. Data for the model parameters are obtained from relevant resources (IEA, World bank, etc.).

Majority of the data gathered for the generation technologies defined in the model are based on the International Energy Agency (IEA) energy balance statistics [24] for the year 2015 and 2016. The following technologies include coal power plants, oil (fuel oil and diesel), solar PV, Concentrated Solar Power (CSP), gas turbine single cycle, gas turbine combined cycle, bio-based generation technologies, wind turbines, geothermal, and nuclear power technology. For these technologies, parameters including the capital cost, fixed cost, capacity factor, and availability factor are used in the model simulation.

3.2 Reference Energy System (RES)

The Reference Energy System (RES) gives a graphical illustration of the energy resource input, transformation, imports and exports and demand in electricity sector. Although, most of the fossil fuel energy resource is used for the generation of electricity, a significant amount of it is also used in heat plants. The remaining portion of these resources includes its utilization in liquefication plants, coal transformation, energy industry own use, transferred through gas networks, and losses [24]. The final electricity demand is divided in the following sectors; industrial, household, and others (transport, agriculture, commercial and public service, etc.)
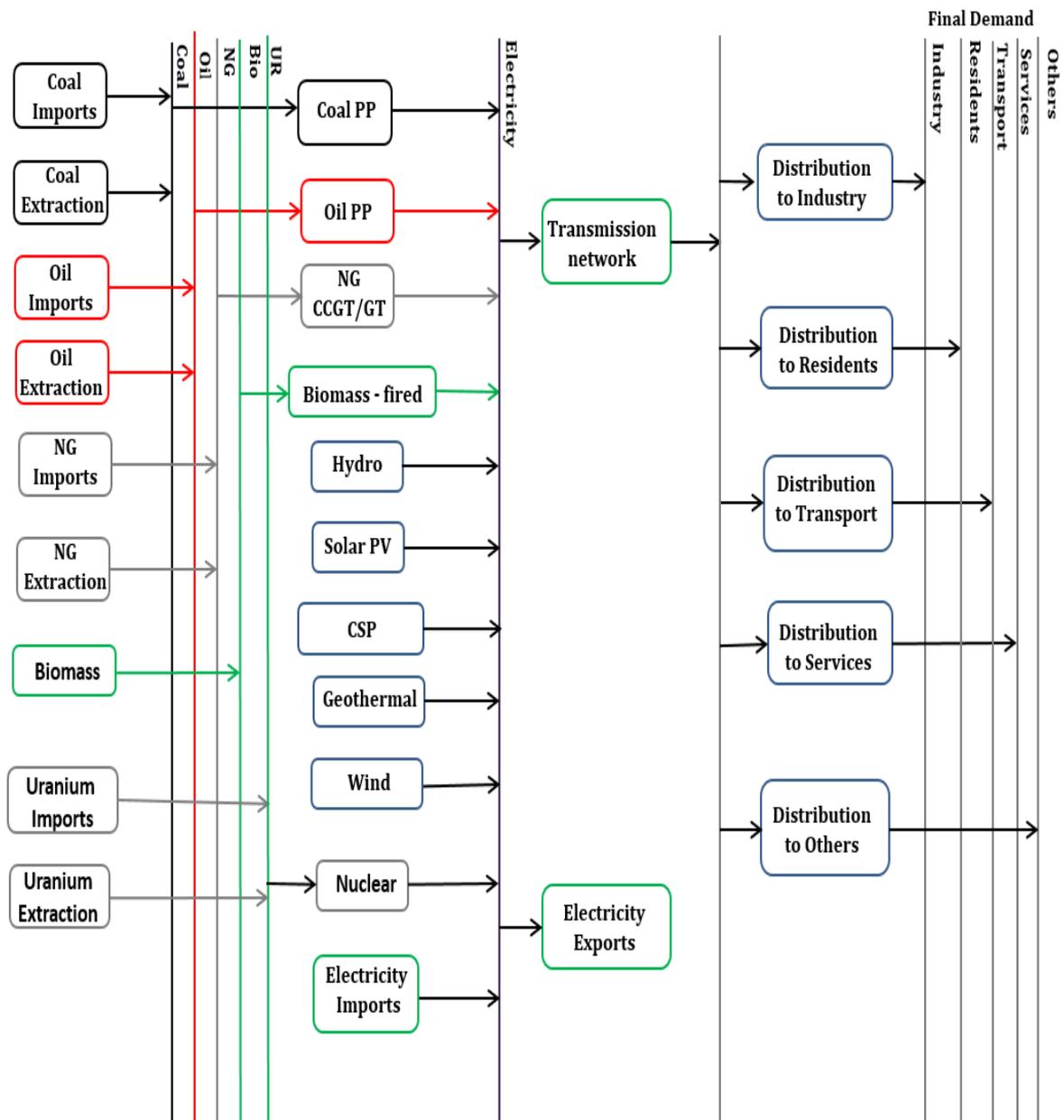
Figure 4: Reference Energy System

4. Scenarios Description

4.1 Reference Scenario (RS)

This scenario is developed incorporating the existing energy plans of China and its national targets such as the 13th FYP related to the country's electricity supply system. In this scenario, the configuration and data for the electricity system in 2016 is used as a baseline for a projection to 2040.

4.2 Renewable Energy Scenario

This scenario analyses the influence of penetration of renewable energy technologies on the energy system. According to the 13th FYP, the set target for solar photovoltaics (PV) is an installed capacity of 105 GW in 2020 [25].In 2017, there was an increase in solar PV capacity of approximately 53.06 GW. By the end of 2017 the total solar PV installations amounted to 130.25 GW which is 24% higher than the solar PV capacity plan in the 13th FYP [26]. Considering this ambitious move in the Chinese electricity sector combined with the high potential of renewable energy resources in the country, assumption is made that electricity production from these technologies (excluding hydro-power) will amount to a 30% share of the total electricity produced in 2040. This scenario, therefore, aims to analyse the implications of these deviations from the planned energy strategy and their influence on the electricity system through to the projected year 2040.

4.3 Climate Change Scenario

Analysis conducted by In the China Renewable Energy Outlook 2017, an analysis carried out by the Intergovernmental Panel on Climate Change (IPCC) suggests to introduce specific emission limits for 2020 and 2030 which will give a greater than 66% chance in achieving the "below 2 degree" climate change goals [27]. The electricity sector represents approximately 37% of the total carbon emissions in China [28]. This scenario, aims to analyse the influence of implementing these emission limits to the electricity supply system of the country.

5. Model Structure

5.1 Assumptions

Some of the key assumptions related to the development of the model are the following:

- A discount rate of 7% [29]
- The electricity consumption pattern [23] is assumed to be equal for all the demand sectors
- Electricity demand projection estimations (section 5.3)

5.2 Power generation technologies

Coal Power plants; Coal remains the dominant source of electricity generation in China. Coal power plant capacities ranging from 6 – 1050 MW per station with majority of the plants with steam turbine configurations and some with cogeneration features. The various forms of coal resources used for power generation are bituminous, anthracite, lignite, and few waste coal from mining or washing operations.

Oil Power plants represents an overall classification of oil products (fuel oil and diesel) used for power generation. Capacities in this division range from 0.6 – 122 MW approximately. These types of power plants have the no projected plans for increased installation capacity in the future.

Gas power plants in China vary in a lot in configuration with the majority of the recently installed types having combined cycle single shaft and gas turbine in combined-cycle CHP configurations. These also includes plants with various forms of gas such as liquefied natural gas, liquified petroleum gas, blast furnace gas. These plants are modelled by subdividing them into two forms; open cycle gas turbine (OCGT) and combined cycle gas power turbine (CCGT) plants. Installed capacities for gas power plants range from approximately 0.06 – 450 MW.

Bioenergy plants represent power plants that utilize the various forms of biomass and biofuels used in China's electricity sector. Biomass materials include wood, agricultural waste, straw and Rice hulls. Power plant capacities range form 6 – 50 MW with ordinary steam turbine only and cogeneration configurations.   Other forms of bioenergy fuel resources used are bagasse, biogas from digestion of agricultural waste or food waste or other organic material, landfill gas, black liquor, and refuse.

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Hydro Power plants, the oldest form of renewable energy generation technology in the country. It represents 20 percent of total installed capacity. Majority of these plants are built in the conventional form with only a small amount integrated with storage technology. Capacities range from 0.25 to 550 MW per station.

Solar PV plants represent the fastest growing renewable energy technology in China. The solar PV installed capacities have already exceeded the target of 105 GW installed capacity by 2020 as described in the latest 13th five plan [25].

Concentrated Solar Power plants constitute a very small portion of the total generating capacity in 2015. However, there are plans to increase this capacity to 5GW in 2020 [25]

Geothermal power; another form of renewable energy resources which utilizes heat derived from the ground to generate electricity. The power generation capacity of this technology was 27 MW in 2015 with plans to increase to 528 MW in 2020 [30].

Wind power represents a large portion of the renewable energy mix in China that plays a major part in transitioning the energy system towards a more sustainable pathway. Most of the wind turbines used in China are horizontal axis wind turbines. Regardless of the substantial curtailments present during operation, the Chinese government has plans to increase wind capacity to approximately 210 GW by 2020 [25]

Nuclear power generation is at a developing stage in the electricity sector. It is another type of clean electricity production technology. The heat produced through by process known as nuclear fission. Unlike the oil-fired generating technologies, there are plans to increase the capacity of this technology to approximately 58 GW by the 2020.Some important techno-economic parameters include fixed costs and capital costs, availability factor, operational life, annual investments, construction time, capacity factor (Appendix,Table **3**) and reserve margin [31]
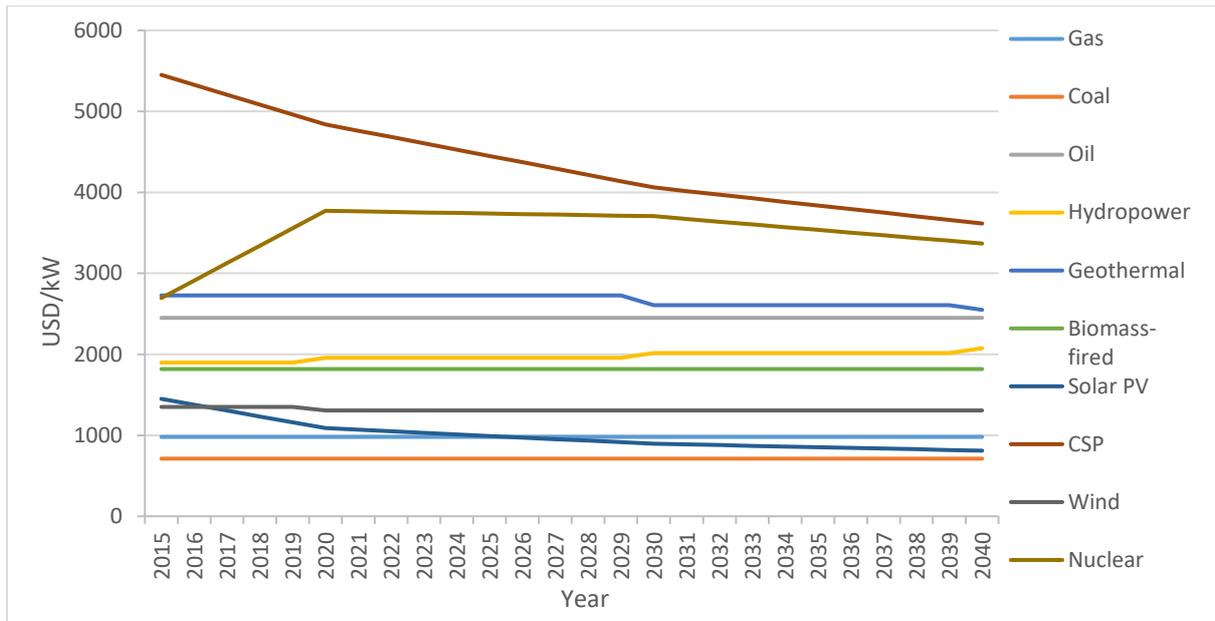
Figure 5: Investment costs of power generation technologies

5.3 Electricity Demand Projections

The baseline data used in this model are mainly extracted from the statistics data of the International Energy Agency [32]. The electricity demand in China was approximately 5000 TWh in 2015 and based on the demand assumptions considered in this model, it is expected to increase to about 9000 TWh in 2040. A breakdown of the electricity demand by sector for the modelling period 2018-2040 can be found in Appendix,Table **4**.

The methodology which was used to project the electricity demands was based on key parameters such as the GDP and population growth rate for each sector for the period 2010 to 2015 used to project the electricity demand . The total demand is formulated using the equation $y = 244.08x + 11149$ where x represents the corresponding year.

The electricity demand is categorized into the following five categories (sectors):

- Industry: This sector has the highest share of electricity consumption. It is expected to increase by 53 percent by 2040 (4960 TWh) compared to the baseline year 2015.
- Transport: It represents the lowest portion of the final electricity consumption and is expected to increase to 440 TWh in 2040.
- Residential: The second highest electricity consuming sector and is projected to reach 1882 TWh in 2040.

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- Services: This refers to both public and commercial services. The electricity demand is projected to increase to 817 TWh in 2040.

- Others: This represents an aggregation of the agricultural/forestry and non-specified electricity demand. The electricity demand is expected to rise to 1038 TWh in 2040.
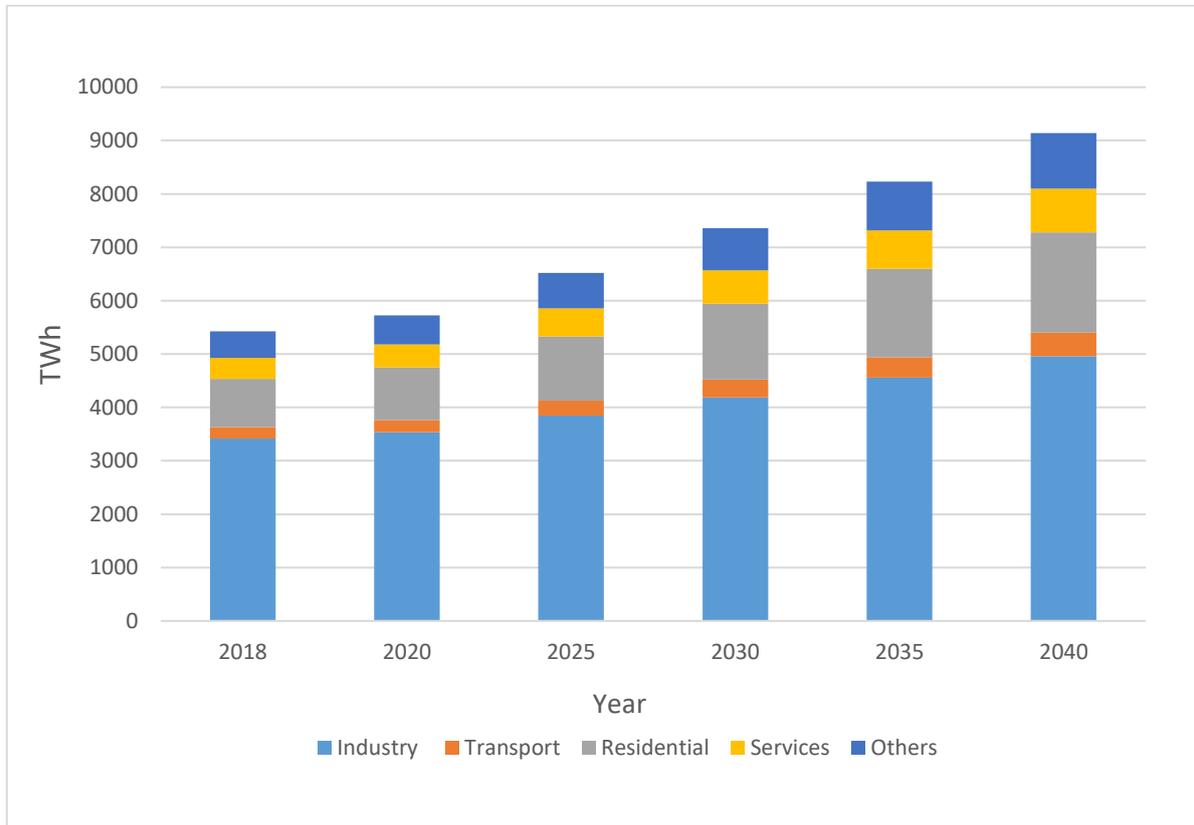
Figure 6: Electricity Demand Projections by sector for the period 2018-2040.

5.4 Emission Activity Ratio

This defines the ratio of emissions produced from a fuel to a unit energy output from the given fuel source. (Table 1) The emission produced by each unit of fossil-fuel used in the model is presented below (Table 1).

Table 1: Emission Activity Ratio [33]

Fuel	Emission Activity (Mton/PJ)
Oil and Oil Products	0.0747
Gas	0.0503
Coal	0.0893

5.5 Fuel Prices, Resource availability and Renewable Energy potential

The fuel prices have been differentiated into local and imported ones. The prices are based on local and international sources. These data are obtained from different references and are included in the optimization model. The prices for the extracted coal are based on the values from the IHS Energy – China Coal Daily publication [34] while the prices of the imported fossil fuel resources including coal, crude oil and natural gas are based on the IEA World energy Outlook 2017 [35]. Local production prices for oil and natural gas are obtained from an article by CNN Money [36]. Locally sourced uranium prices [37] and importation prices [38] vary significantly. Biomass is also produced locally and its use in power production is also in an evolving stage. A common price [39] is assumed for all types of biomass utilized in this sector. The fuel prices considered into the model can be found in Appendix Table 2

Although China is one of the largest crude oil producers, the use of oil products (fuel oil and diesel) used in electricity production is very low and it is expected that this will remain unchanged in the future. Natural gas on the other hand represents a significant portion of fuels used in the electricity sector with plans to considerably increase its use in the future.

China has a high renewable energy potential (Hydro, Solar, Wind, etc.) (Appendix Table 5) with wind energy having the highest potential of an upper limit of about 24700 TWh/yr (88920 PJ/yr).

6. Results

In this section, the results obtained from this analysis are presented. In addition, a comparison between the scenarios is presented indicating the major research outcomes.

6.1 Reference scenario

The Reference scenario shows an increase in total installed capacity of approximately 2733.7 GW in 2040 compared to an approximate capacity of 1500 GW in 2015 [40]. The installed capacity of coal power plants decreases from approximately 58% of the total installed capacity in 2018 to 17% in 2040There is an increased trend of coal power capacity from 2018 till it peaks at 2020, it then remains constant (that is no new capacity is added) for five years and begins to drop in 2026 as these plants begin to retire. Natural gas is the only fossil fuel

resource with an increased use in the electric power generation. Capacity of natural gas technologies grows from 73.7 GW in 2018 to 362 GW in 2030 and to 510 GW in 2040. Fuel oil decreases from 16.3 GW in 2018 to 9.7 GW (a share of less than 1%in 2040). Hydropower still constitute most of the capacity of the renewable energy technologies, 547.84 GW in 2040, representing 20 % of the total capacity the same year. Wind technology represents the second largest installed renewable energy technology, 19% in 2040 followed by solar pv accounting for 18% of the total capacity in 2040. The rest of the renewable energy technologies (biomass, CSP, geothermal) grow steadily amount to only 1.12% of the total capacity in 2040. Nuclear energy also represents a significant share of 6.8% of total capacity in 2040.
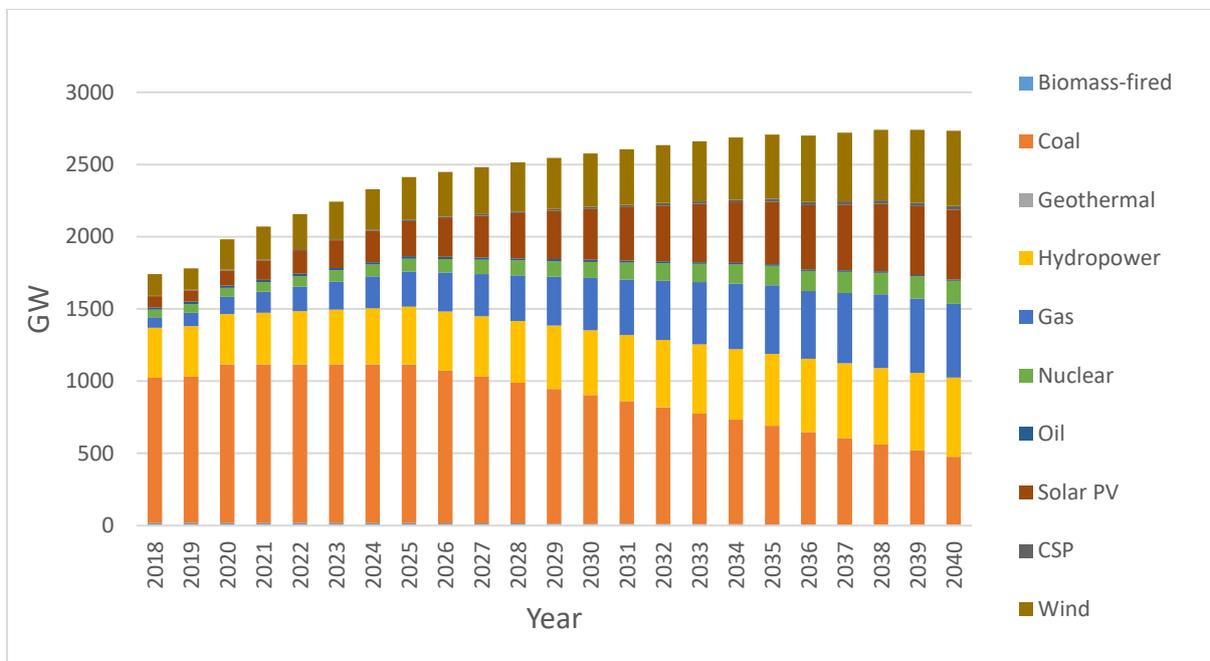

Figure 7: Installed Capacity (Reference Scenario).

In the Reference scenario, the total electricity production increases to 38,311 PJ in 2040. The share of coal power generation falls to 33% in 2040 as Gas-fired technologies produces 16 % of electricity generation in the same year. It serves as a replacement to the declining electricity generation of coal power technologies. Hydropower contributes the highest share of non-fossil power generation and is followed by Nuclear energy. Electricity production from these plants show increasing patterns which is mainly influenced by the competitive and technology related factors (availability and capacity factors) of these technologies through to

the projected year 2040. Nuclear electricity generation accounts for 11 % (4247.53 PJ) in 2040, compared to the generation capacity of 1399.2 PJ in 2018. Solar PVs and wind technologies generate most of the renewable electricity but account only for 8.8 % and 6.4 % of total generation in 2040 respectively. CSPs, and geothermal power plants generate the lowest electricity share of 2.5% and 0.03% respectively in 2040.
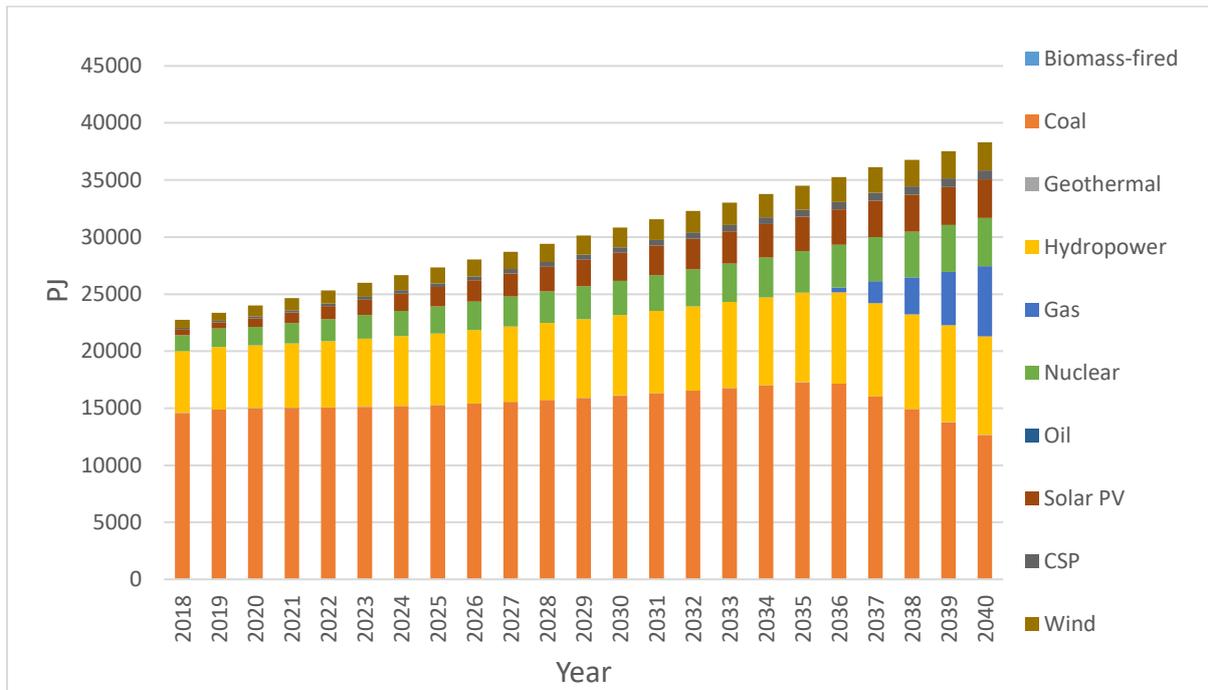

Figure 8: Electricity Generation (Reference Scenario)

6.2 Renewable energy scenario

In this scenario, in 2040, the total capacity increases by 22 % (3322.44 GW) above the total capacity recorded in the reference scenario. In 2040, the renewable energy capacity grew from 1583.23 GW in the reference scenario to 2172 GW in this scenario (37% increase). The increased generation from renewables results in solar pv capacity accounting for 33.7 % of total capacity in 2040. Wind energy capacity increases steadily and accounts for 12.8 % share while other renewable energy technologies such as CSPs, biomass-fired, and geothermal plants amounted to 0.8 %, 0.2 %, 1.4 % respectively in 2040. Hydropower accounted for 14% of total capacity in 2040 to become the second largest installed renewable energy capacity in the same year.

Coal and gas-fired power accounts for 14% and 15 % of total capacity respectively in 2040 while fuel oil amounted to only 0.29% share in the same year. There is also a significant rise

in Nuclear energy investments in this scenario. Nuclear energy capacity rises from a share of 3% of total installed capacity of 1746 GW in 2018 to 4.8% of total capacity in 2040.
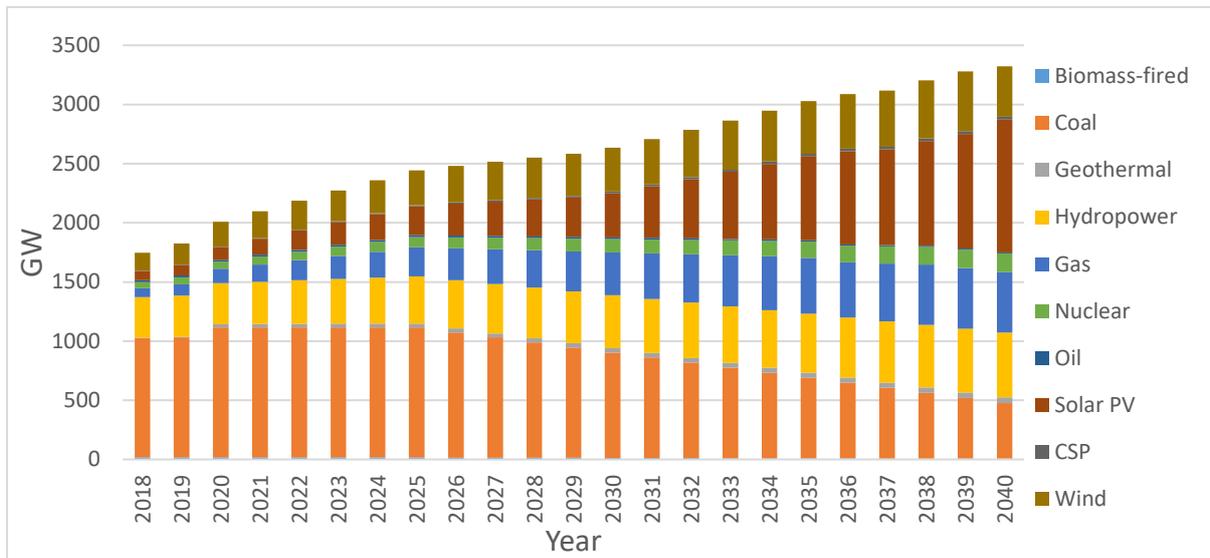

Figure 9: Installed Capacity (Renewable Energy Scenario)

The figure 10 below shows a decline in coal generation to a share of 33% (12655 PJ) of total generation of 38311 PJ in 2040 as the penetration of renewable energy technologies increases. A slightly flat trend in coal power generation can be observed for most part of the period of projection, however the overall electricity generation from coal in this scenario is 10% lower than that of the reference scenario. Gas power plants accounts for approximately 1.5 % of the total production. This is a result of the higher availability factors and lower capital costs associated with these technologies. Nuclear generates 11% of total generation in 2040. Hydropower remains the highest supplier of electricity from non-fossil fuel resources with a share of approximately 23% in 2040. Electricity generation from other renewable technologies grows with Solar PV generating 20% and is followed by wind power which amounts to 5% of total electricity generated in 2040. Biomass – fired power plants also experiences an increase in electricity production to a share of about 0.2% while geothermal and CSP represents a share of 3.8% and 2 % respectively in 2040.
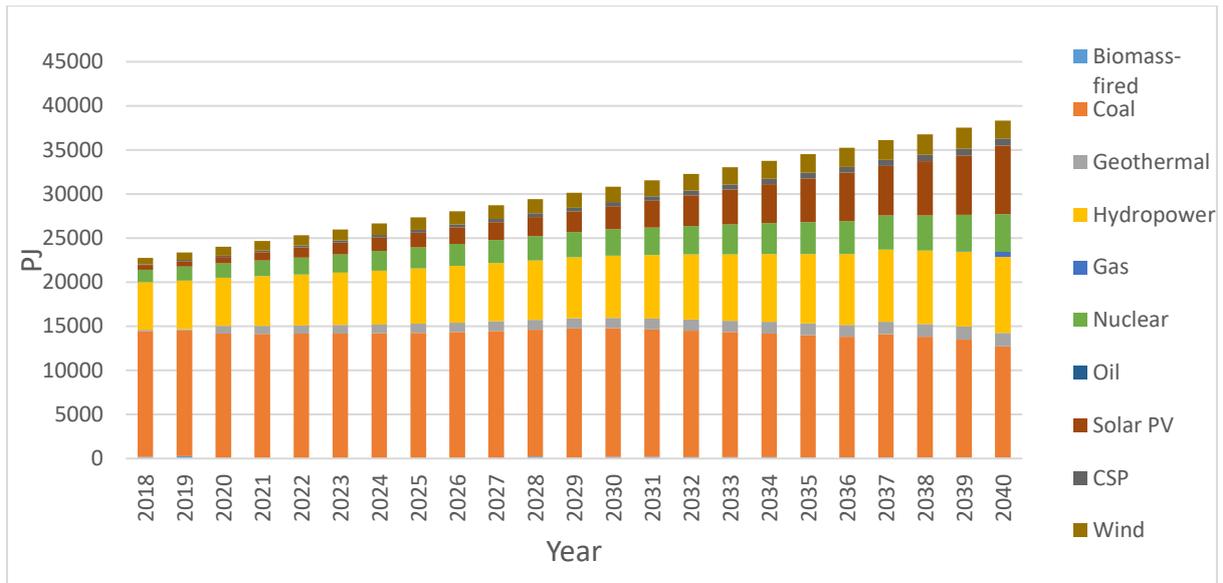
Figure 10: Electricity Generation (Renewable Energy Scenario)

6.3 Climate Change scenario

The total installed capacity (figure 11) for the Climate Change (CC) scenario amounts to 2862.7 GW in 2040. In 2040, the coal power capacity declines to a share of 16.5% of the total capacity. Natural gas capacity increases and amounts to a share of 22% of total installed capacity in 2040, representing the highest fossil fuel base capacity while oil-fired power capacity accounts for only 0.34% share in the same year. In this scenario, nuclear power hydropower is the largest non-fossil fuel capacity with a total capacity of 548 GW, and is followed by wind energy and solar pv with shares of 18.2% and 16.9 % respectively in 2040. Nuclear energy amounts to 5.5% of the total capacity in 2040. The remaining power generation technologies; geothermal, CSPs and biomass-fired amounts to 0.26%. 0.87%, 0.18% of total installed capacity in 2040.
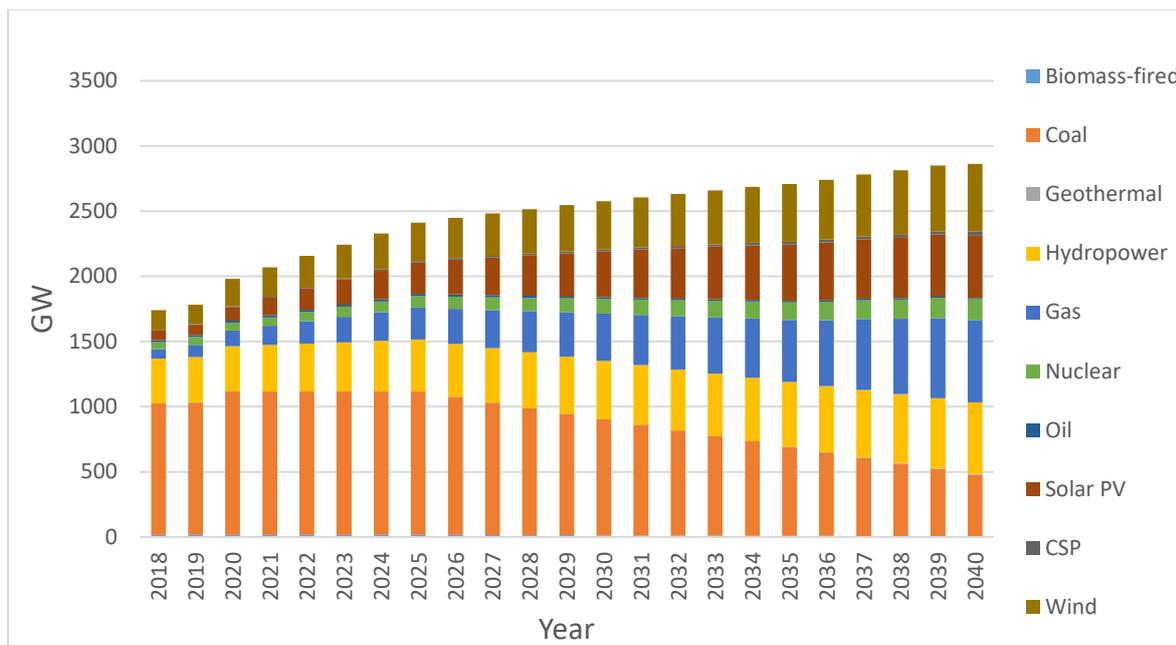
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Figure 11: Installed Capacity (Climate Change Scenario)

In 2040, the total electricity generation (38311 PJ) remains the same as that of the Reference Scenario. Gas fired power plants generates the highest amount of electricity (12834PJ) in 2040 and acts as the main substitute to the rapid decline in coal-fired power generation. Total fossil fuel based electricity generation amounts to approximately 49% share of total generation in 2040, constitutes of 34% natural gas and 15 % coal-fired generation. Hydropower occupies a share of 23% of total electricity generation in 2040 and produces the highest non-fossil based electricity in 2040. Nuclear represents approximately 11% of total generation in 2040. Solar PV and wind power amounted to 8.8% and 6.4% share of total generation in 2040, while CSPs and geothermal technologies accounted for 2.1%, 0.6% share of total electricity generation in the same year. In this scenario, the total electricity generation from renewable energy technologies such as, amounts to approximately 41% share in 2040.
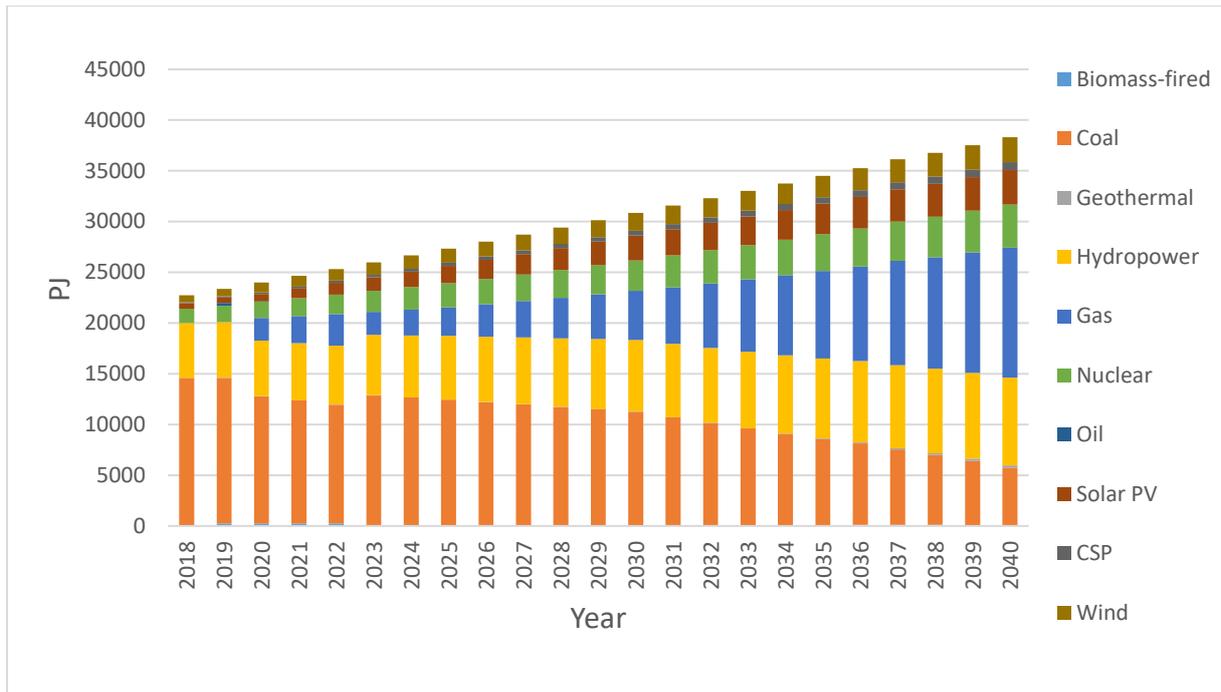
Figure 12: Electricity production (Climate Change Scenario)

6.4 Scenario comparison

6.4.1 Carbon dioxide emissions comparison

This section includes an examination on the pattern of emissions produced by all three scenarios. In the reference scenario (RS), an increase in emissions is observed till it peaks in the year 2035. This is primarily driven by the plans for an increased installed capacity of coal power plants in the Chinese electricity policies. Afterwards, emissions begin to decline as these coal plants retire and production from these plants decreases with a simultaneous increase in electricity production from renewable energy technologies and gas power plants (lower carbon intensity). Although emissions shows a declining trend in the year 2040, they are still approximately 66% above climate change levels in the same year.

The Renewable Energy (RE) scenario which illustrates the higher penetration of renewable energy technologies shows a lower trend in CO_2 emissions compared to the reference scenario. However, a fairly flat pattern is observed for the emissions produced in this scenario up until the year 2033. The rapid increase in renewable energy technologies translates to a higher investment costs for these technologies thereby allowing coal power generation to remain competitive within the period from 2019 to 2033. Afterwards, emissions decline up until the year 2040, but is only 8.3% lower than emissions recorded in the reference scenario

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in 2040. However, emissions in 2040 is 51% above climate change levels and the continuation of this trend shown in this renewables scenario suggests that emissions will only attain climate change levels in 2047.

The Climate Change (CC) scenario sets emissions cap for the year 2020, and 2030 through to 2040. The figure below shows the emission pattern for the climate change scenario. To to achieve climate change emissions targets, total CO_2 emission recorded within the period of projection for RS and RE must drop by 24% and 16% respectively. It is observed that the largest difference in CO_2 emissions of approximately 1.8 Gtons occurs in 2036 between the reference scenario and the climate change scenario but reduces to about 1.3 Gtons in 2040.
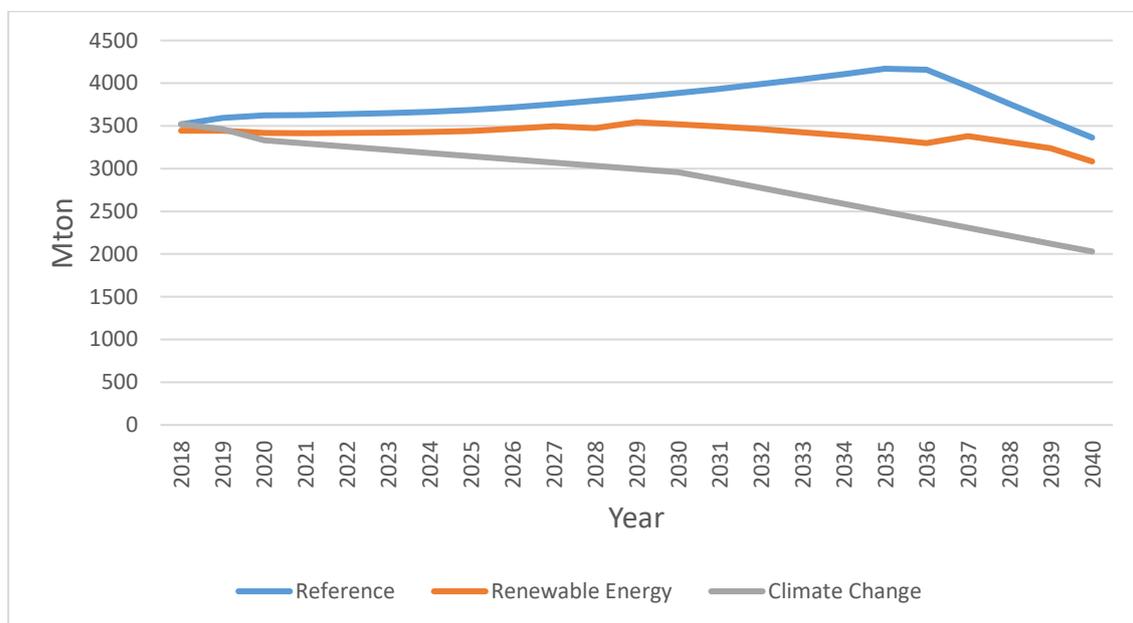
Figure 13: Annual emissions (All scenarios)

6.4.2 Non-fossil fuel base generation

The share of electricity generation produced from non-fossil fuel technologies in the reference, renewable energy and climate change scenarios is presented in Figure 14. In 2040 there is approximately 52%, 65% and 51% share of non-fossil base electricity production for the reference Scenario, renewable energy scenario and climate change scenario respectively. The major driver of the high percentage of non-fossil based electricity production in the renewable energy scenario is the rapid increase in installation of Solar PVs and increased production from other renewable energy resources.

From the figure below, it can be observed that the reference scenario and climate change scenario produces a similar pattern. For climate change scenario, it is the case that the rapid decline in coal power generation in replaced by lower carbon intensive gas powered electricity supply, thereby keeping the share of fossil based generation about the same as that of the reference scenario. This is majorly driven by the cost competitive nature of gas fired power plants compared to most of the renewable energy technologies. However, as climate change goals become more stringent, this may not be the case.

In 2040 non fossil base electricity supply in the renewable energy scenario achieves a share of 65% (25071 PJ) of total electricity supply compared to 37% (8477 PJ) recorded in 2018. Both the reference and climate change scenario show an increase from 36% (8163 PJ) share of total electricity supply in 2018 to 51% (19520 PJ) and 52% (19741 PJ) respectively in 2040.
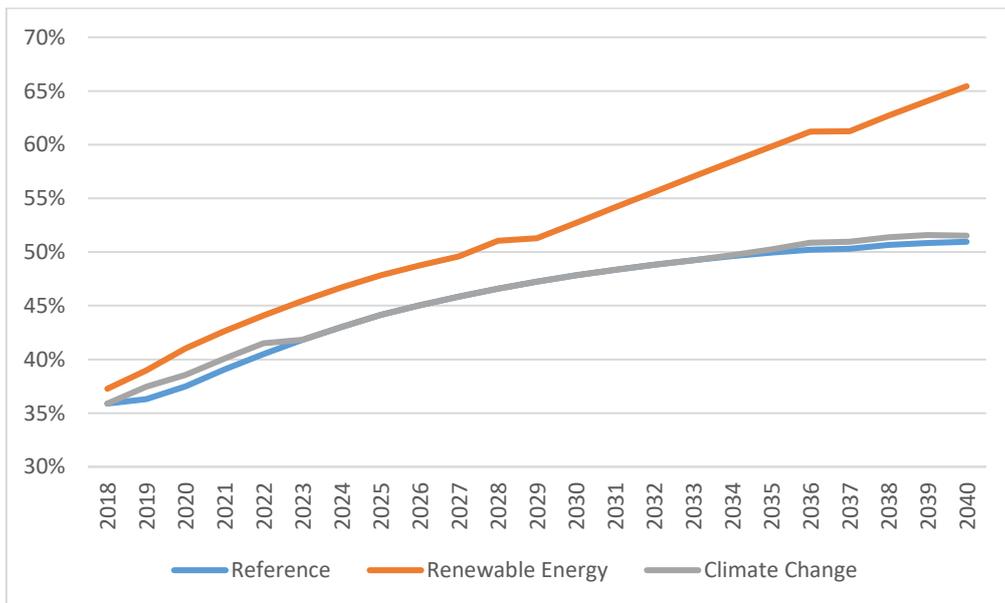

Figure 14: Percentage of non-fossil fuel Production

Conclusion

This research has been conducted based on the 13th five year plan, ongoing ambitious penetration of renewable energy technologies and climate change goals, to provide insights on the reaction of the constituting technologies and emissions produced from the electricity supply system in China.

The outcomes of this study show that the current energy plans (13th five year plan) for China's electric sector are not sufficient in meeting climate change goals. The proposed 13th five year plan for the electricity sector contradicts with the climate change goals in the country as it proposes an increased installed capacity of coal-fired power generation plants. Further actions are required for implementation. In addition, a higher penetration of renewable energy technologies does decrease emissions but is still insufficient in meeting climate change goals in the short term, if other effective measures such as the decommissioning of high emitting coal-fired power plant are not implemented.

The Climate Change scenario indicates that Hydro power plant will continue to play a major role in the electricity supply in China. Nuclear energy could also be a viable option to achieve lower emissions in the electricity sector. Therefore, the Chinese government should consider setting more ambitious targets investing on this type of technologies while taking into account some drawbacks including the high costs of fuel waste management [41]. In the replacement of other fossil based generation, natural gas represents a viable option as a result its high reserve capacity and a lower emission factor compared to that of coal power generation.

The outcomes of this study shows that achieving emission limits to attain climate change goals in the Chinese electricity sector seems to be far-fetched in the short term. However, one solution to mitigate this challenge, in addition to the elimination of the plans to increase coal power capacity is the utilization of the existing overcapacity plagued by the sector.

Limitations and Future Work

Some limitations and areas for future work will be discussed in this section. In this thesis, parameters used to model the demand for each sectors were limited to the gross domestic product (GDP) and population growth rate of the country. A more specific approach could be considered for future research, for example, incorporating factors that represent the reduction

in energy intensity in the industrial sector, the use of more efficient appliances in the residential sector and the shift towards a more electrified transport sector. This thesis is also limited to an analysis of three scenarios. In future studies, other scenarios related to the implementation of the new emission trading scheme [42], technology advancement (increased efficiencies and capacity factor, bioenergy with carbon capture and storage (BECCS)) of power generating technologies, changes in fuel prices, growth rate of electricity consumption detailed for each demand sector can be considered. The conclusion of this thesis proposes Nuclear energy as a viable option to achieving climate change goals in the country. However, the model only considered the major techno-economic parameters (fuel cost, investment cost, etc.) for this technology. To get a deeper understanding of the practicalities of this technology, further studies can include other influencing parameters such as expensive costs of safe disposal of radioactive waste and decommissioning this type of power plant.

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Appendix

Table 2: Fuel Extraction and Import Prices [34], [35], [36], [37], [38], [39]

Fuel	Price(USD/GJ)					
	2015	2020	2025	2030	2035	2040
Oil Extraction	4.82	3.70	5.44	6.17	6.90	7.63
Natural gas Extraction	7.78	5.97	4.17	4.17	4.17	4.17
Coal Extraction	3.18	2.11	2.25	2.34	2.43	2.53
Uranium Extraction	2.22	2.78	3.33	3.33	3.33	3.33
Biomass Extraction	2.23	2.23	2.23	2.23	2.23	2.23
Oil Import	13.87	10.63	15.65	17.74	19.84	21.94
Natural gas Import	7.01	7.44	9.86	10.08	10.30	10.52
Coal Import	4.23	2.81	3.00	3.12	3.24	3.37
Uranium Import	0.31	0.31	0.31	0.31	0.31	0.31

Table 3: Techno-economic parameters for Power Generating Technologies [43]

Technologies	Capital Cost (USD/kW)			Fixed Cost ($/kW)		
	2015	2020	2040	2015	2020	2040
OCGT	381.1	381.1	381.1	20	20	20
CCGT	598.9	598.9	598.9	20	20	20
Coal-fired	711.4	711.4	711.4	20	20	20
Oil	2450.0	2450.0	2450.0	66.7	66.7	66.7
Hydro	1897.1	1956.4	2015.7	40	40	40
Geothermal	2727.1	2727.1	2608.5	45	45	45
Biomass-fired	1818.0	1818.0	1818.0	55	55	55
Solar PV	1449.7	1087.3	861.3	14	12	12
CSP	5450.4	4838.6	3882.0	200	166	130
Wind	1350.2	1306.7	1306.7	30	30	30
Nuclear	2694.5	3772.3	3570.2	120	120	120

Table 3 (continued): Techno-economic parameters for Power Generating Technologies [43]

Technologies	Life (Yrs)	Construction time (Yrs)	Availability Factor (%)	Capacity Factor (Average) [44]
OCGT	20	2	85	-
CCGT	20	2	85	-
Coal-fired	40	3	85	-
Oil	35	2	80	-
Hydro	50	4	Varies	50
Geothermal	30	4	85	-
Biomass-fired	40	3	50	-
Solar PV	25	1.5	Varies	22.2
CSP	25	2.5	90	-
Wind	20	2	Varies	20.3
Nuclear	35	7	85	-

Table 4: Projected Annual Electricity Demand (TWh) **[24]**.

Sector [TWh]	2018	2020	2025	2030	2035	2040
Industry	3417	3533	3845	4185	4556	4959
Transport	212	231	282	334	387	440
Residential	905	988	1205	1428	1655	1882
Services	393	429	523	620	719	817
Others	499	545	665	788	913	1038

Table 5: Fossil-fuel Reserves **[45, 46]**.

Fuel	Reserve	Units
Coal	138,819	million metric tons
Natural gas	5.194	trillion cubic metres
Oil	25.62	billion barrels

Table 6: Renewable Energy Potential **[47]**

Technologies	Potential (TWh/yr)
Wind	88,920
Hydro power	21,898.8
Solar PV	23,328
CSP	30,000
Geothermal	1000
Biomass	10,500