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MSc Program
Environmental Technology & International Affairs

Prospect of Sustainable and Secure Energy in the People's Republic of China

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Prof. Dr. Günther Brauner

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Vienna, 01.06.2016

Affidavit

I, **ANTON LEVSTEK**, hereby declare

1. that I am the sole author of the present Master's Thesis, "PROSPECT OF SUSTAINABLE AND SECURE ENERGY IN THE PEOPLE'S REPUBLIC OF CHINA", 72 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

Energy has played an important role in China for achieving its impressive growth rates and the rapid industrialization of past decades. However, the cheap energy supply came from heavily polluting energy generation methods using fossil fuels, primarily coal. Severe pollution has made the Chinese energy regime highly unsustainable, with adverse effects on the environment and the health of the population. China has realised that a way to overcome this problem is the promotion of the utilization of renewable energy and the government has made their first efforts. Moreover, the country has to engage actively in ensuring energy security. Particularly, oil consumption is growing, which makes China increasingly dependent on oil imports, the prices of which can be at times volatile and unreliable. Also for this case, renewable energy promises to be a fruitful option. This thesis explores the capacities and possibilities the Chinese government has in renewable energy deployment and the environmental and economic benefits such a change would bring. Furthermore, decentralised energy, as the energy paradigm of the future, being highly economic and efficient, is analysed in the specific case of China. Moreover, flue gas treatment methods are presented, being indispensable in any case in the short-term perspective and being an important preliminary step to halt the deterioration of the already vulnerable environmental situation of the country.

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Acknowledgements

To my parents and Yerin for their continuous support

1. Introduction

1.1. Introduction and Relevance

China has come a long way since the establishment of the People's Republic of China (PRC) in 1949. At this time the country was one of the poorest countries in the world, struck by famines, civil wars and invasions from the outside. Over the course of the 20^{th} century, China experienced explosive growth from 1978 onwards and is today the country with the second highest GDP after the United States. But besides having a stable and flourishing economy, the country also emerged as a major player in international politics and more than ever influences world trade. The Chinese success story, however, has also a dark side. Pollution and environmental degradation have become major obstacles to the Chinese economy and to a healthy development of the Chinese society. Severe air pollution in major cities has become an everyday problem and dealing with the ecological impacts of dammed rivers has become normal business. The environmental degradation of the country should not only be concerning for the Chinese government and society, but is also of huge relevance on a global scale. While the international community struggles to come to effective solutions with regards to reducing greenhouse gas (GHG) emissions and other pollutants, the coal fired power plants in China are still exhausting their smoke. The People's Republic of China is responsible for almost 24 % of global GHG emissions, which are 10,975.50 Million tons of CO_2 equivalents. (World Resources Institute 2014) The numbers highlight the relevance of the Chinese emissions with regards to climate change. As a country with rapidly growing energy demand and per capita incomes it will be very important to reduce emissions in China in order to effectively combat climate change. Particularly the implementation of renewable energies and emission reduction technologies will have to be promoted, as reducing demand will be difficult, given the huge population of the country, which will likely rise further.

China is part of the Kyoto Protocol, but has as a non-Annex B country no binding targets to reduce emissions. However, it would be misleading and unfair to demonize China by branding it as the dirty economy, as it has been done by several media platforms, such as bloomberg.com and Al Jazeera. (Bremner 2006; Al Jazeera 2011) Firstly, it should be mentioned that the per capita GHG emission are still considerably lower in China than in most developed nations. Secondly, a country hosting nearly one fifth of the world population is naturally emitting a tremendous amount. Thirdly, and most importantly, China is still on its path of becoming a developed nation. Its economy was for a long time based on cheap labour and energy intensive industries. Only recently the country shows signs of maturing economy such as increasing wages and a growing middle class with a growing consumption of goods. Furthermore, many countries, also in the western world, went through periods of extensive pollution, until technologies were implemented, but also industries outsourced in order to reduce environmental harm. Often these industries were outsourced to East Asian countries, amongst which China seemed often as the most popular and promising host.

This is not to excuse the absence of pollution reduction technologies and sustainable production of energy. Energy production, mainly from fossil fuels, is a major driver of environmental degradation in China. The leadership of the country has to recognize the opportunities and benefits a switch to more sustainable energy production will bring both to the economy and society. Otherwise the effects on the population and nature will be devastating and more irreparable harm will be done than is already the sad reality. The government already took first steps in implementing measures in connection to efficiency, sustainability and the promotion of renewable energy. Time will tell how effective their efforts will be.

Another aspect to China’s rapid economic growth is the topic of energy security. As the energy demand is rising, but energy supply is partly insufficient and the energy systems inefficient, the government will be forced to find other ways of covering the demand. Some regions suffer from energy shortages, which may lead to disapproval from the population and are economically suboptimal. Chinas increasing dependence on fossil fuel imports is also a challenge which the government is currently facing. Ideally, new energy supply would come from renewable sources, because it would also tackle the environmental problem. Both the environmental and the energy security dimension are drivers behind the government’s current efforts to modernize and revolutionize the existing energy regime.

This thesis will explore the various possibilities and opportunities that the Chinese government has to reduce the environmental degradation of the country from the production of energy and how it can produce this energy more sustainably. It will show how energy production from renewable sources, decentralisation and the use of emission reduction technologies will benefit the PRC from an environmental, but also an economic perspective. At the same time the aspect of energy security will not be lost of sight and ways will be shown up how renewable energy and decentralisation of energy systems can support to achieve energy security and increase energy efficiency. However, the thesis will also consider obstacles, limitations and difficulties to such a change. At the end of the thesis I will summarize my results and give recommendations for a sustainable future energy regime in the People's Republic of China.

1.2.Research Question:

RQ: "How can China achieve a more environmentally sustainable energy regime, while at the same time ensure energy security?"

2. Country data

2.1. Geography and Population:

China is a country located in the East Asian region and covers the area spanning from parts of Northeast to central Asia and is bordering to Southeast, South Asia and the Pacific Ocean. With a size of 9.596.960 square kilometres China ranks as the 4th largest country in the world. The coastline of the country amounts to 14.500 km. The terrain of the country is to a large extent mountainous with high plateaus. The western part of the country has a lot of desert area, while the very eastern parts consist of plains and delta regions. The big size of the country, which spans over several climatic zones, makes the climate diverse, ranging from tropical in the south to subarctic in the north-eastern parts. (fig. 1). Among the most important natural resources of the country are coal, iron ore, petroleum, natural gas, arable land and waters with hydropower potential. Only 22.3% of the land is covered with forests, while agricultural land amounts to 54.7 %. (CIA 2016) The best wind resources for power generation are found in the northwest and northeast. (IRENA 2014: 2) Furthermore, with its long coastline China has also considerable offshore wind capacities. The best usable solar resources are found in the southwest and northern part of the country. (IRENA 2014: 50)

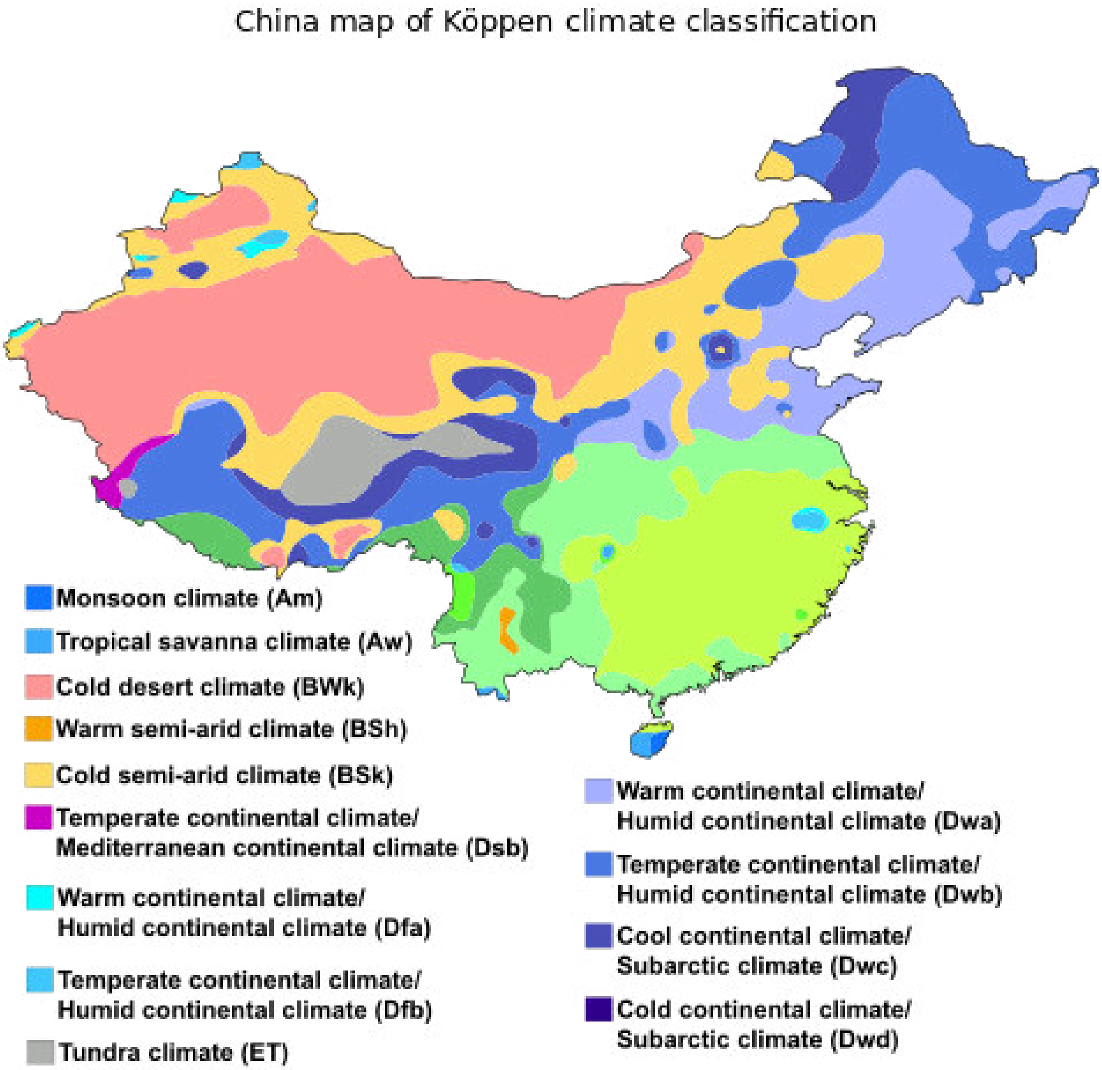

Fig.1. China map of Köppen climate classification (Source: Zifan 2016)

China is the most populous country of the world. The population currently amounts (2014) to over 1.364 billion people (World Bank 2016d). Population growth rates were considerably low when compared to other developing countries and economies in transition. Since the beginning of the new century until today the population growth rate averaged around 0.6 %. (World Bank 2016f) However, for such a huge country even small percentages mean a significant increase of people in absolute terms. It should be noted that the one child policy was officially abolished in 2015 and replaced by a "two child policy". (Buckley 2015)

2.2.Macroeconomic data

Since 1978, when Deng Xiaoping started to introduce capitalist market principles China's economy grew immensely (around 10% average GDP growth for the last 30 years). (World Bank 2016c) Before this great shift to trade liberalization China was a planned economy, which can be nowadays characterised as very poor, stagnant, centrally-controlled, vastly inefficient, and relatively isolated from the global economy. The reforms then suddenly catapulted the Chinese economy forward by opening the country to foreign trade and investment. Since that time China was amongst the world's fastest growing economies. Today China is a major global economic power, manufacturer, merchandise trader and holder of foreign exchange reserves. (Morrison 2015: 2-7) Chinas GDP increased almost 10-fold between 2000 and 2014, from around 1 trillion to over 10 trillion US-Dollars at current market prices. (World Bank, 2016c) The enormous increase of China's GDP since the mid-70s until today is outlined in fig. 2:

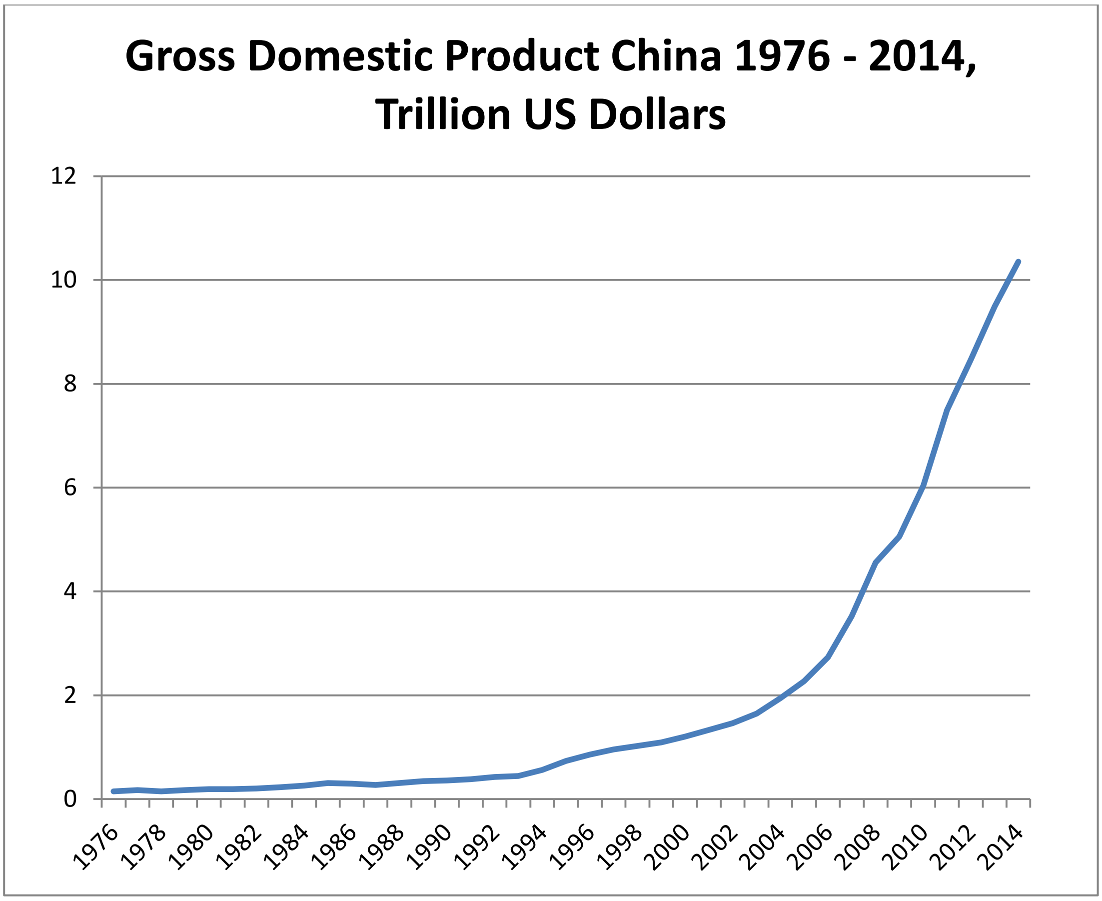

Fig. 2 Gross domestic product in Trillion US Dollars (Source: World Bank 2016c)

However, this then strong and stable economy was strongly affected by the global economic crisis in 2008. The important exports, imports and inflows of foreign direct investment started to decrease. The GDP growth slowed down significantly and millions of Chinese workers lost their employment. Although the government reacted promptly by taking measures to mitigate for the effects of the crisis such as implementing a $586 billion economic stimulus package and loosening monetary policies to increase bank lending, the economy has slowed down in the recent past. Reasons for this are radical slowdowns of export and fixed investment growth rates. (Morrison 2015, ii)The country's real GDP growth decreased from 10.6% in 2010 to 7.6% in 2012, to 7.2% in 2014. (World Bank 2016b). The IMF projects that China's real GDP growth will slow to 6.3% in 2016. (Morrison 2015, ii) Recent GDP growth rates of China's economy are outlined in fig. 3.

Fig. 3 (annual GDP growth China (%) 1998 - 2014) (Source: World Bank 2016b, annual growth GDP growth)

While it is true that the PRC's economic growth has been slowing down in recent years, this can be seen as a sign that the country is moving from a developing to a developed economy. (Economy Watch, 2013) As China's technological development begins to approach that of major developed countries (also through adoption of foreign technology), its level of productivity gains, could slow significantly from its historic levels unless China becomes a major hub for new technology. (Morrison, 2015: 7)

Recognising this, the Chinese leadership has announced to change the current economic model of fast growth. The focus in the new economic model should be the reduction of their reliance on energy-intensive and high-polluting industries and the shift to more high technology, green energy, and services. (Morrison, 2015: 8)

3. Energy security and sustainability

In order to provide a description of the scope for the examinations of the thesis it is important to define the theoretical framework it is based upon. For the purpose of the thesis it is important to distinguish between energy security and energy self-sufficiency. Furthermore, the term sustainability will be explained, as it is being increasingly used with slightly different meanings in various disciplines.

3.1.Energy security

The International Energy Agency defines the term energy security as the *"the uninterrupted availability of energy sources at an affordable price"* (IEA 2016). The IEA further distinguishes between two dimensions of energy security:

> *"long-term energy security mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs. Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance. Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile." (IEA 2016)*

Additionally the energy security definition of von Hippel links the energy directly to national security:

> *"A nation state is energy secure to the degree that fuel and energy services are available to ensure:*
>
> *i) survival of the nation,*
> *ii) protection of national welfare, and*
> *iii) minimization of risks associated with supply and use of fuel and energy services" (Von Hippel et al. 2011: 6724).*

In addition, it should be noted that traditionally energy security has been seen by countries and also national and international energy institutions, such as the IEA, as securing the access or supply to fossil fuels, such as oil and coal. As global energy markets increasingly diversify and the hazards stemming from energy usage become more and more transnational, however, the view on energy security will have to start to cover a wider area. Not least of all, climate change, environmental and economic considerations will play an important role in shaping a more comprehensive perspective on energy security. Globally the greatest environmental problems stemming from energy consumption, especially from fossil fuel consumption, are acid rain, trans-boundary air pollution and global climate change. In particular, climate change will pose a great challenge to energy policy. Technical emission reduction measures such as the use of flue gas desulfurization devices, which aim to reduce the emissions of acid rain precursors and greenhouse gas emissions, will not be sufficient to successfully combat climate change and it will require more than "end of pipe" technologies to face the challenge. Furthermore, the problem of climate change will have to be addressed on a significantly longer time perspective than enterprises and governments are used to dealing with. (von Hippel 2011: 6719-6723)

Recognizing the need of future energy security policies to address environmental harm, this thesis will work with a view on energy security, which includes environmental issues and takes into account the notion of sustainability.

At this point it is important to separate the term energy security from energy self-sufficiency. Self-sufficiency is commonly seen as the state where a system requires no external support or interaction for survival. In the case of energy this would mean that all energy that is consumed is produced within the country from resources, which also originate entirely from that country. This implies the absence of imports, for instance. Energy security, however, is mainly concerned with the security of supply (also through imports) and the sustainability of energy. Therefore, a country does not have to be energy self-sufficient in order to achieve energy security.

In the case of China energy security was always an important topic. Until the early 1990s, China considered itself as energy self-sufficient, as it was still producing its energy almost entirely by domestic sources and was a net exporter of oil. Efforts in the area of energy security addressed the increase of supply in coal and moderating demand through energy efficiency. Since the early 1990s however, China eventually became a net importer of oil and the energy demand kept rising further. (van der Hoeven 2013: 11-13) As the demand is not likely to significantly drop, energy security efforts manifest in the limitation of imports, diversification of supply routes and efficiency enhancement. However, imports will still be rising in the future and the return to energy self-sufficiency will be a very unlikely scenario, while environmental harm is taking on severe dimensions. Therefore energy security efforts will have to also concentrate of the increase of energy production from renewable energy sources. . (van der Hoeven 2013: 11-13)

3.2.Sustainability

The definition of sustainability used in this thesis will be the one provided by the United Nations in 1987 by the Brundtland report, as it addresses both the environment and the economic well-being of nations, for the present but also for the future.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland 1987: p.14)

This definition is particularly relevant and useful for the area of energy, as production and consumption are directly related to the environment. As energy production requires natural resources and puts pressure on the nature and the environmental services required for the well-being of society (present and future), sustainability should be an integral part in energy policy making and in the energy debate in general. Furthermore, in the case of fossil fuels natural resources are limited, so here also economic and energy security considerations for the future of a country play a major role.

4. Energy Sector Profile China:

Coal is the keyword when examining the Chinese energy sector. It has been the major energy source since the establishment of the PRC and it still remains the main fuel of the Chinese economy until today. The exploitation of coal has been secured throughout the decades by the government.

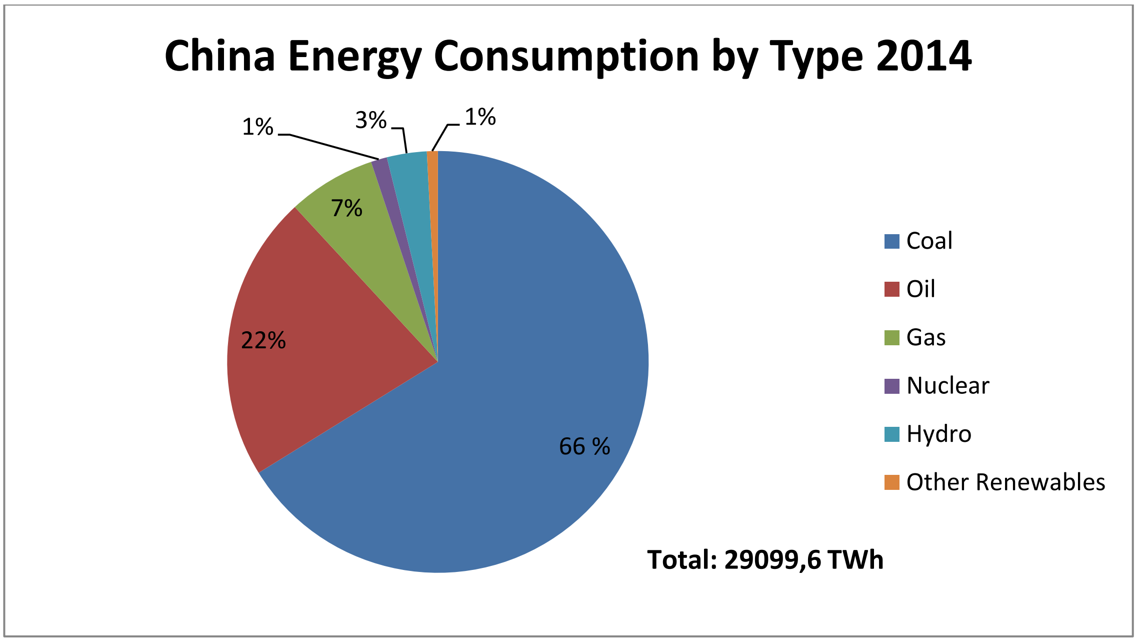

Fig. 4. China Energy Consumption by Type 2014, (Source: The Shift Project Data Portal 2016)

Globally China is the largest consumer, producer and importer of coal. The great economic growth has been achieved mainly on the basis of this form of energy utilisation. Until today more than two thirds of Chinese primary energy supply is served by coal (fig. 4). It is predicted that China will consume more coal than the rest of the world combined over the next two decades, while the coal demand growth will only start to decline after 2035. This downward trend will not be solely attributable to the shift in renewable energy, but also to a slowdown in economic growth and the rebalancing of economy away from heavy industry, efforts in diversification of the fuel mix in the power sector, efforts in CO_2 emission reduction and aims to improve air quality and increase energy efficiency. (IEA 2014: 291 ff.)

Electricity demand in China grew at a faster rate (12% per year) than anywhere else in the world during the last decade. However, as the economy is gradually maturing and the pace of industrialisation is slowing down the growth of the energy demand is also decelerating. It is predicted that electricity demand will grow only at a rate of 2% from 2021-2040 onward, which would be in the magnitude of industrialized countries. In comparison energy demand growth rates of the United States and the European Union are 0.8% and 0.6% respectively. (IEA 2014: 230-234)

In terms of energy demand per capita the country is still using much less energy than industrialised western nations. In China per capita annual electrical power consumption amounts to 3,762 kWh, while in Germany to 7,019 kWh and in the United States almost to 13.000 kWh per capita. (World Bank 2016a) In absolute terms the Chinese economy on a whole consumes 5.322 trillion kWh (status 2013, 5320 TWh) of electric power.

Although a relatively new player in the field, China is currently the biggest investor in renewable energy worldwide. In the year 2013, 60 GW of renewable energy capacity were added, of which one half was made up by solar photovoltaic and wind energy (IEA 2014: 192). 2013 was also the year where the new capacity added from renewables was higher than that of fossil fuels.

5. Environmental Problems in China

The rapid growth, the immense industrialisation of the Chinese economy explained earlier, lead over the decades to serious environmental problems, accompanied by deteriorating health among the population. China is the country with the highest carbon emissions and was the source for 27% of the world's total greenhouse gas emissions already in 2014. (Xu, 2014).

Over more than half of a century the environment deteriorated continuously with little action being taken by the government or enterprises in charge. Furthermore, urbanisation continued to intensify after the 1970s, putting additional pressure on nature and the environmental services that are required to support the economy and society. The result of these developments was an over-proportionate consumption of natural resources such as arable land and the generation of pollutants at an increasingly unsustainable rate. This exploitative behaviour is also attributable to a labour-intensive economic model that makes use of resources in an inefficient way. Two other very important aspects which have to be brought in connection with the environmental degradation in China are energy and population growth. Between 1952 and 1990 the Chinese population grew annually by 1.83 % on average and between 1990 and 2010 by 0.22% on average. However, at the same time this population growth was accompanied by average capita income growth rates of 6.7 for the period from 1952 to 1990 and 19.7% for the period from 1990 to 2010. The increases in annual per capita income amounted to 4.9% and 7.1%, respectively. This led to an increase in total energy consumption and coal consumption by 15.1 % from 1952 to 1990, and by 22.9% from 1990 to 2010. Also emissions of industrial pollutants increased significantly: 14.9% annually from 1952 to 1990 and by 12.2% annually from 1990 to 2010. It should be highlighted that the emissions from industrial pollutants grew faster than the Chinese economy in these periods, which had wide and severe ecological implications. (Luo Chunyan et al. 2013: 199 -200)

Air pollution: With energy consumption increasing in the PRC, smog levels are also skyrocketing in the country. Particularly cities are affected by air pollution. 16 of the 20 most polluted cities in the world are in the PRC and less than 1 percent of the 500 largest cities in the PRC can fulfil the WHO's air quality standards. (Xu, 2014)

In Beijing in early 2013 for instance pollution levels were 30 times higher than levels deemed safe by the World Health Organisation (WHO). (Kaiman, 2013)

What is very problematic about smog is the fact that it has a relatively high concentration of particulate matter 2.5. Particulate matter are small particles that are of such small size that they can penetrate the lungs and enter the bloodstream leading to health problems such as asthma, lung cancer, respiratory infections, cerebrovascular disease and damaging children's development. Smog is a serious health threat in the PRC. (Ibid.)

The major sources for the severe air pollution in cities like Beijing are the manufacturing industries and the coal fuelled electric power plants that supply the Chinese economy with energy. (Lallanilla, 2013) Coal is also the main source for the country's high sulphur dioxide levels and particulate emissions. (Xu, 2014) A 2014 OECD report estimated the health costs of China's air pollution in 2010 at $1.4 trillion. (Morrison, 2015: 35)

Water pollution and scarcity: One of the greatest environmental threats is water pollution and depletion. There are serious shortages of drinking water as overuse contamination and waste reduce the amount of drinking water. Two thirds of China's cities do not have sufficient water at their disposal although the PRC controls the river supply of thirteen neighbouring countries. In rural areas the consequences of water shortages are even more severe. Around 300 to 500 million people on the countryside do not have access to piped water. Furthermore, the water supply itself has been severely polluted in China, because industry tends to be situated among the major water supplies in the country. In 2014 around 90 percent of underground water in urban areas and 70 percent of inland water bodies in the PRC were already polluted. It is estimated that the total cost, which arises from water scarcity arising from pollution amounts to 1 percent of the GDP of the PRC. (Xu, 2014)

Desertification is also strongly linked to water pollution. As a result of the overuse of water rivers are drying up and the polluted water that is left is increasingly useless for agriculture. (The Economist, 2013)

Land degradation: Land deterioration is posing another serious threat to China's environment, population and economy. 40 percent of the arable land in the PRC is affected by degradation. This severely reduces the country's capacity to produce food. In the northern Heilongjiang province, which is regarded as China's food basket, the fertile black soil is thinning out. In the southern part of the country however, farmland is affected by acidification. The reasons for land degradation are usually reduced fertility, changes in acidity and the consequences off climate change and pollution. Particularly the area of Beijing will face food supply problems in the future, as vast pollution of water and land are the direct consequences of the city's rapid industrialization of the past decades. (Patton, 2014)

Climate change: Climate change is a concerning issue for China, because it seriously increases the threat of natural disasters in the country. Average temperatures of the earth's surface in China have increased by 1.1 degrees Celsius. It is predicted that China's average temperatures will rise by 3.5 degrees Celsius by the end of the 21st century. The effects of climate change are diverse in China, because of its great size and geographical differences. (Lai, 2009) Of course, China is not the only one to be held responsible for global climate change. However, the problems resulting from its effects, might be an incentive to enhance China's efforts in contributing to the combat of global climate change. The four major effects of climate change in China will be briefly discussed below:

1. *Melting of Glaciers:* If temperatures continue to increase glaciers will melt down, which will lead to the flooding of glacial lakes into the upper reaches of the Yangtze River. This would cause large scale floodings and mudslides in mountainous areas. Different regions already experience an increased frequency and destruction through mudslides. (Ibid.)

Furthermore, the water volume of the two major rivers, the Yangtze and Yellow River will be reduced as a consequence of shrinking glaciers. These two rivers are to a great part provided with water by glaciers. Several smaller rivers that are running from the mountain regions are connected to the great rivers. If, due to the shrinking of glaciers theses small rivers are not able to reach the two great rivers anymore their water volume will decrease significantly - in the case of the Yangtze River a 25 percent decrease of water is likely. The shrinking of the Yangtze River on the other hand would lead to the desertification of wetland ecosystems along the river. (Ibid.)

2. *Rising sea levels:* Rising sea level, due to the meltdown of the ice caps are particularly problematic in China as urbanization along China's coastal zones is rapidly increasing. In the case of Shanghai and Tianjin, for instance, sea level rise is even higher than normal, because of decreased land load carrying capacity, which is a result of the high concentration of buildings and their over-extraction of groundwater. In the case of Hong Kong, which is located on the typhoon belt of the South Pacific Ocean, sea level rise will also increase the destructive power of typhoons causing massive flooding in coastal areas, the overall frequency of typhoons is also expected to increase in Hong Kong as a result of sea level rise. (Lai, 2009)

3. *Loss of Biodiversity:* Although urbanization and pollution are the main reasons for biodiversity loss in the PRC, climate change also plays a significant part in these developments, because it is altering the structure of ecosystems. The decreases of rainfall and temperature changes are a threat to the habitats and food sources of animals, such as the giant panda. Furthermore, due to climate change coral reefs along China's coastal zones are also threatened. The main reasons for this are rising sea surface temperatures and rising levels of carbon dioxide, which causes ocean acidification and coral calcification. (Ibid.)

4. *Increase of natural disasters:* China has experienced an increase in abnormal natural disasters, such as tropical cyclones, rain storms, dust storms, increased frequency and intensity in extreme climate phenomena, such as high temperatures, heavy rain and snow and severe droughts. Furthermore, not only the frequency with which typhoons occur is increasing, also their strength, speed and destructiveness are growing. The consequences of this are devastating damages to residents on the coastal zones, particularly in the southeastern part of the PRC. Droughts on the other hand are being increasingly recorded in northeastern China, which leads to further water scarcity problems. (Ibid.)

6. Legal and Economic Background of Energy Sector

The regulation of energy is central in the development process of the PRC. Energy industries are important to ensure independence and security of a country. However energy regulation and legislation in the PRC took on different shapes as the country went through different economic and political transformations since its establishment. (Xi and Li, 2012)

6.1. Overview

The management of renewable energy in China takes place on two different levels. There is a combination of centralized administration on one level and decentralized administration of practical implementation at local levels by the requisite department. The administrative departments responsible for renewable energy are the National Energy Administration (NEA) and the National Development and Reform Commission (NDRC). They have the tasks of setting the medium- and long term total volume targets for renewable energy throughout China, compiling national renewable energy development and utilization plans and publishing the Guidelines for the Renewable Energy Industry. However, as renewable energy resources, technologies and utilization are complex and diverse a large number of departments and ministries are involved in the management system for renewable energy. The most important departments, which mainly focus on the research and development, demonstration and deployment; wind and solar resources assessments; environmental assessments and financial incentives of renewable energy deployment are the Ministry of Science and technology (MOST), the China Meteorological Administration (CMA), the Ministry of Environmental Protection (MEP) and the Ministry of Finance (MOF). On the other hand, departments such as the Ministry of Water Resources (MWR), Ministry of Land Resources (MLR), the National Forestry Administration (NFA), the Ministry of Housing and urban Rural Development (MOHURD) an the State Oceanic Administration (SOA) deal with the management and development of different types of renewable energy. Officially, the administration of renewable energy is centralised under the National Energy Administration. However, in practice the management of renewable energy is still decentralized and localized. (Wang 2014: 197-199) This leads to the fact that renewable energy developers have to get approvals from many different departments with sometimes overlapping or conflicting competencies. The result of this is that the complex management systems lead to low efficiency and sometimes too difficult obstacles for enterprises and investors to get engaged in the field of renewable energy.

1950s - 1980s

Until the 1980s the planned economy model was in place in the PRC. Accordingly, the regulations in this model also applied to the energy sector. In this period the leaders of the PRC gave special importance to fuels. Consequently, the Ministry of Fuel Industry (MFI) was established to deal with regulations in the electricity, coal and oil industries. The exact responsibilities of the MFI, according to the 1950 Organic Law of the Fuel Industry, were to decide on development plans for the fuel industry, approving the structure of operational plans of enterprises. Furthermore, it was given the task to organize enterprises construction and production, which included finance, materials, and technology. Moreover, importance was given to human resources by providing research, educational initiatives with a focus on fuels and the training of technicians. (Xi and Li, 2012)

In accordance with the planned economy model and its mission, the MFI elaborated monthly energy production plans for each producer in the energy sector. Moreover, the MFI was in charge for the allocation of equipment and raw materials to the producers. These producers in turn had to fulfil the orders and targets set out by the MFI. Since the whole energy sector was dictated by the government, there was practically no market for energy. Consequently there was no need for energy regulations or extensive energy laws, because energy enterprises were not market players but the recipients of orders. Thus in the 1950s - 1980s the energy sector was not really controlled by laws but rather by administrative orders and energy production plans. (Ibid.)

1980s -1990s

In this period, the PRC went through an economic transition period, which started in 1978 with the economic system reform. The aim of the system reform was to transform the PRC from a planned economy to a market economy. China experienced an immense economic development process after the reform. However, energy shortage problems also became clear. Furthermore, despite the fact that the country started to introduce the market economy, the energy firms including their investments and operational costs were still under total government control and dependent on the government support. Because the government invested only relatively little into the energy sector, it developed only sluggishly. The legislation of the government focused in the transition period rather on opening the energy market in order to ensure that a wide range of different actors enter the market. One example of these diversification efforts by the government in the energy sector is the introduction of the principle that any player could invest in a power plant in 1985. However, the government still had the authority and control over the power grid. (Ibid.)

The economic transition period can be seen as the beginning of elaborate energy legislation in China. Although many of the provisions introduced in this period are rather general principles they have to be seen as a milestone for the energy sector legislation in the PRC. In this period, the government realised that proper laws and legislations are needed in order to effectively regulate the energy market. The result of the transition period was that the energy sector was not under the complete government control anymore but included rather a mix of government activity and market mechanisms. However, it should be pointed out that in this period energy legislation in the PRC was still influenced strongly from the times of the planned economy. (Xi and Li, 2012)

2000s - Present

In the new millennium, the PRC's energy sector faces challenges of a different form than in the decades before, where the aim was to develop the energy industry and introduce the market economy into the energy sector. The country developed rapidly in the 21st century and the market dominates the economy. However, this rapid development also brings about undesirable consequences such as high energy consumption, environmental problems and pollution. As a result, the Chinese government started to focus on sustainable development, energy conservation, emission reduction and renewable energy in its energy legislation, partly also due to international and internal pressure. At the centre of these efforts is the Renewable Energy Law from 2005 (amended 2009). (Ibid.)

6.2. Special Importance of Renewable Energy

China's energy policy was for a long time concentrated on energy supply security. Environmental regulations accompanying the usage and production of energy where severely neglected. (Xi and Li, 2012)

Renewable energy first addressed in the year 1996 under the Electricity Law:

> *"The construction, production, supply and utilization of electric power shall protect the environment according to law, adopt new technologies, minimize discharge of poisonous waste, and prevent pollution and other public hazards. The State encourages and supports electricity generation by using renewable and clean energy resources."* (Electric Power Law of The People's Republic of China, The People's Republic of China, 1995 Asian Legal Information Institute, 2016)

Unfortunately, as the provisions in Article 5 of the electricity law had more the shape of general provisions and also enforcement power and implementation rules were lacking, the renewable energy sector had only developed minimally. (Xi and Li, 2012) As a consequence, The Renewable Energy Promotion Law of 2005 was developed. This law was passed in order to promote the development and utilization of renewable energy to improve the country's energy structure, ensure stable energy supply, and prevent pollution and ecological damage as a result of the strong increase in the usage of fossil energy. (Ibid.)

> *"Article 1: This Law is enacted for the purpose of promoting the development and utilization of renewable energy, increasing the supply of energy, improving the structure of energy, safeguarding the safety of energy, protecting environment and realizing a sustainable economic and social development."* (Ministry of Commerce, People's Republic of China, Renewable Energy Law of the People's Republic of China, 2013)

It is the first renewable energy legislation with this kind of focus in the PRC. In 2009 the law was further amended. The law contains five central management mechanisms. These are the following:

1. Total amount control: This provision states the development targets the government sets out for a certain time period. This, in turn, is an incentive to the market

and promotes with that the exploration and utilization of renewable energy. (Xi and Li, 2012)

2. Mandatory grid connection: This provision states that all power grid enterprises are obliged to purchase all of the renewable energy available to them. Furthermore, the provision reduces transaction costs for renewable energy. Moreover, it abolishes market entrance barriers for producers of renewable energy. (Ibid.)

3. Categorized electricity pricing: Under this provision it is permitted that the various types of renewable energy can each set up their own prices, which are based on the average social costs of each type. (Xi and Li, 2012)

4. Cost allocation: Under this provision it is required that each region allocates the additional cost of producing renewable energy in a fair manner. The idea is that the energy producers should not have to absorb the whole extra costs for generating renewable energy. (Xi and Li, 2012)

5. Special funds: This provision is focused on the establishment of special funds which should deal with the problems of additional costs in the production of renewable energy. Furthermore, the special funds are set up to provide financial support, for instance in the form of subsidies, to certain renewable energy projects, the costs of which cannot be completely distributed to all market players. (Ibid.)

Tax Incentives

Another important part of the renewable energy law is the offering of financial incentives in order to promote the development of renewable energy. An important tool in this context is Implementing Regulations for PRC Enterprise Income Tax Law, which came into effect in 2008. The law focuses on firms, which are engaged in undertakings in the field of energy conservation and improvement of emissions reduction technology. According to the law, such enterprises are exempted from tax for three years and then are only required to pay 50 % of the total tax rate for enterprises for another three consecutive years. The use of such financial tools can be seen as proof that the Chinese government is truly committed to enhance the development of renewable energy by creating a conductive environment for investment. (Su et al. 2010: 28-30)

Emissions trading and Carbon Caps

The PRC also promotes missions trading, similar to the emissions trading system in the Kyoto Protocol. The aim of emissions trading in China is to enhance efficiency and cut emissions in the country's heavy industry sector. The government expects improvements in air quality and a reduction of the country's share of global carbon emissions. Furthermore, in five of seven provinces a system of absolute caps on emissions was introduced. (IRENA 2014, p. 45-46)

Mandatory Market Share (MMS)

Connected to the mandatory grid connection under the renewable energy law the National Development & Reform Commission (NDRC) introduced the mandatory market share (MMS) in 2007. For regions supplied by centralised power grids the MMS policy set out targets how much power should be generated form non-hydro renewable sources. In 2010 the target was a share of 1 percent and by 2020 3 percent of total power generation. In the case of power generating firms with a capacity higher than 5 GW the share of non-hydro renewable energy from total energy production should have reached 3 percent and 8 percent by 2020. However none of the largest companies in the PRC succeeded to meet the 3 percent non-hydro renewable energy target in 2010. Reasons for this are that there is insufficient monitoring and a lack of compliance requirements. An improvement plan, which the NDRC started to work on in 2011 should improve monitoring in the future and specify targets for companies on an individual basis. (Ibid..: p. 36-37)

6.3. Special Importance of Oil

Oil plays a major role in today's energy politics in China. Since the early 1990s China is a net oil importer, and the demand after oil kept continuously rising since then. (See fig. 6.) China's oil demand is predicted to increase at an annual average rate of 2.2 % until 2035 and the country will likely surpass the United States as the largest oil consumer in the late 2020s. The IEA predicts that over the next quarter century China would account for around 50 percent of the rise in global oil demand. (van der Hoeven 2013: 11 f.) The main reason for the rising demand of oil in China is the over-proportionate consumption of petroleum products for transportation, but also construction and residential activities play a role. The increased consumption of oil for transportation is explained by increasing urbanisation, higher per capita incomes and a corresponding growth in the private vehicle fleet as shown in fig 5. (Hunter 2010: 7). The fundamental problems with China's oil demand are that the country's oil production does not keep pace with the demand (see fig. 6.) and that the supply routes are not sufficiently diversified, which makes the Chinese economy dependent on certain suppliers. Until the early 2000s the Middle East was the most important source for Chinese oil imports. However, the 9/11 attacks and the outbreak of the second Iraq war, made the government realise that it had to diversify its export routes, as the Middle East was not seen as a secure supplier anymore. (Hunter 2010: 13). The government reacted promptly and new strategies were developed to cope with the oil problem. Several energy research institutes were brought together by the Development Research Centre of the State Council to develop a comprehensive energy strategy. The result was a set of reports called 'China National Energy Strategy and Policy', published in 2004.

Oil security, according to the NESP *"entails guaranteeing that the country's demand for oil (which is necessary for the sustainable development of both economy and society) is met in satisfactory terms as regards quality, quantity and price."* (Hunter 2010: 14)

While oil insecurity *"refers to potential damages on the country's economy due to temporary and abrupt supply cut-offs, broader shortages, or price shocks."* (Hunter 2010: 14)

As a result, the NESP came to the conclusion that, non-OPEC petroleum suppliers will play an increasingly important role in oil export such as Russia, Norway, Mexico and some West African countries. Furthermore, it was found that both petroleum consuming and exporting countries are diversifying their export and import routes to stabilize demand or supply, respectively. (Hunter 2010: 14) China realised that oil supply might suffer from temporary shortages and short-term local shortages. Also violent short-term fluctuations in oil prices were recognised as a concern, as a high oil price may reduce China's GDP growth rate and a low oil price my lead to losses in the domestic oil sector. Furthermore, natural or other disasters may have negative impacts on the production or supply of oil. As a consequence, the NESP recommended China diversify its oil import sources, focusing on Latin America, Russia, central Asia, countries in the Caspian Sea area, but also on the Middle East, which is predicted to remain the most important oil import source until 2030. Furthermore, it was recommended that domestic oil companies should engage in more upstream investment, such as oil exploration, both in China and abroad. (Hunter 2010: 15-22) Upstream investment describes in the oil industry investment into ("upstream") operational stages, which focus primarily on the exploration of oil. Upstream enterprises locate, test and drill for the oil reserves. If reserves are proven these companies extract the oil from the reserve. (Investopedia 2016)

A very important aspect of China's oil policy is also the engagement of Chinese oil companies abroad, which is part of China's "go abroad" strategy. This policy which was introduced by the leadership in 2002 supports foreign direct investment of Chinese firms abroad, both financially and politically. The aims of that policy, which are especially important with regards to oil are to secure resources, acquire technology and to gain access to established distribution networks. (Hunter 2010: 17)

A result of this go abroad strategy is the increasing presence of Chinese oil companies in developing countries, especially in Africa. Natural resources are the main incentive of China's engagement on that continent. As early as 2003, already one fourth of Chinese oil imports came from the continent. (Tull 2006: 466) The strategies to secure oil supply from Africa include debt relief, grants, non-interest loans and foreign aid to African countries. In return, however, these loans are conditional, as they are tied to Chinese companies, which are obliged to use Chinese products for the projects. Similarly, the repayment of loans is often tied to the export of oil to China, such as is the case with Angola. (van Dijk 2009: 16) Furthermore, there is a significant amount of foreign direct investment from Chinese enterprises in accordance with the go abroad strategy, which insures risky investments of domestic firms. (Six and Perchtaler 2009: 15)

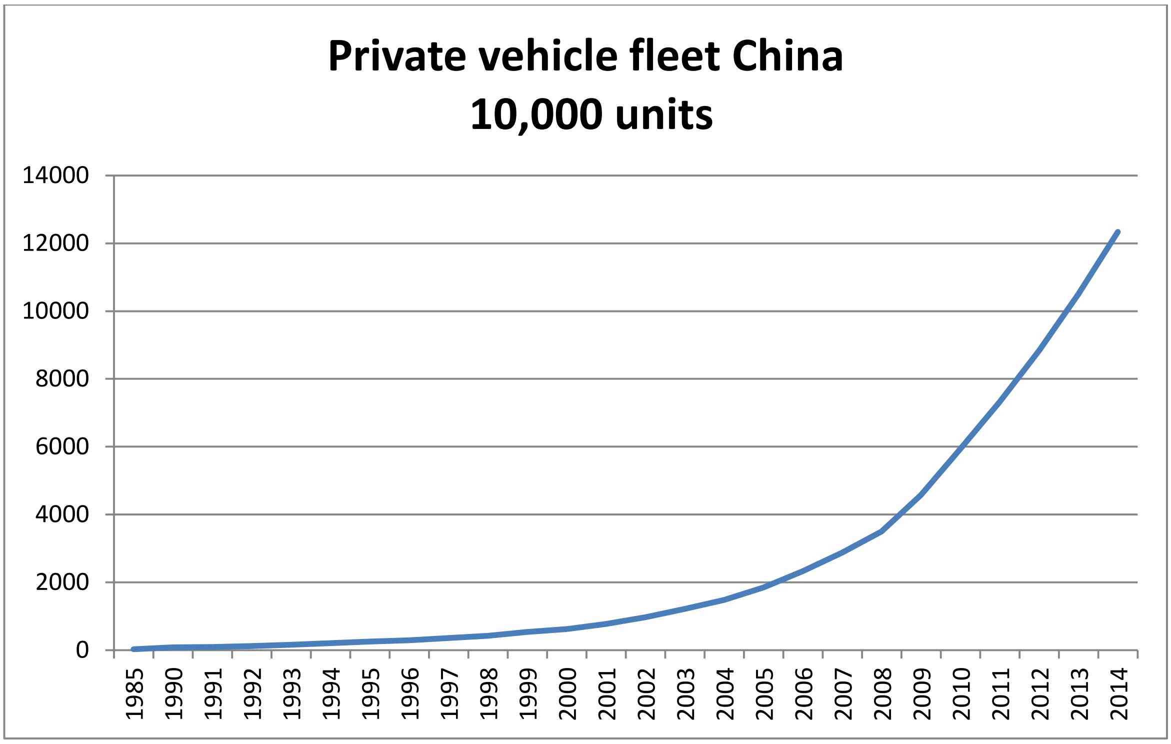

Fig. 5. Private vehicle fleet China in 10,000 units, (Source: China Statistical Yearbook 2015)

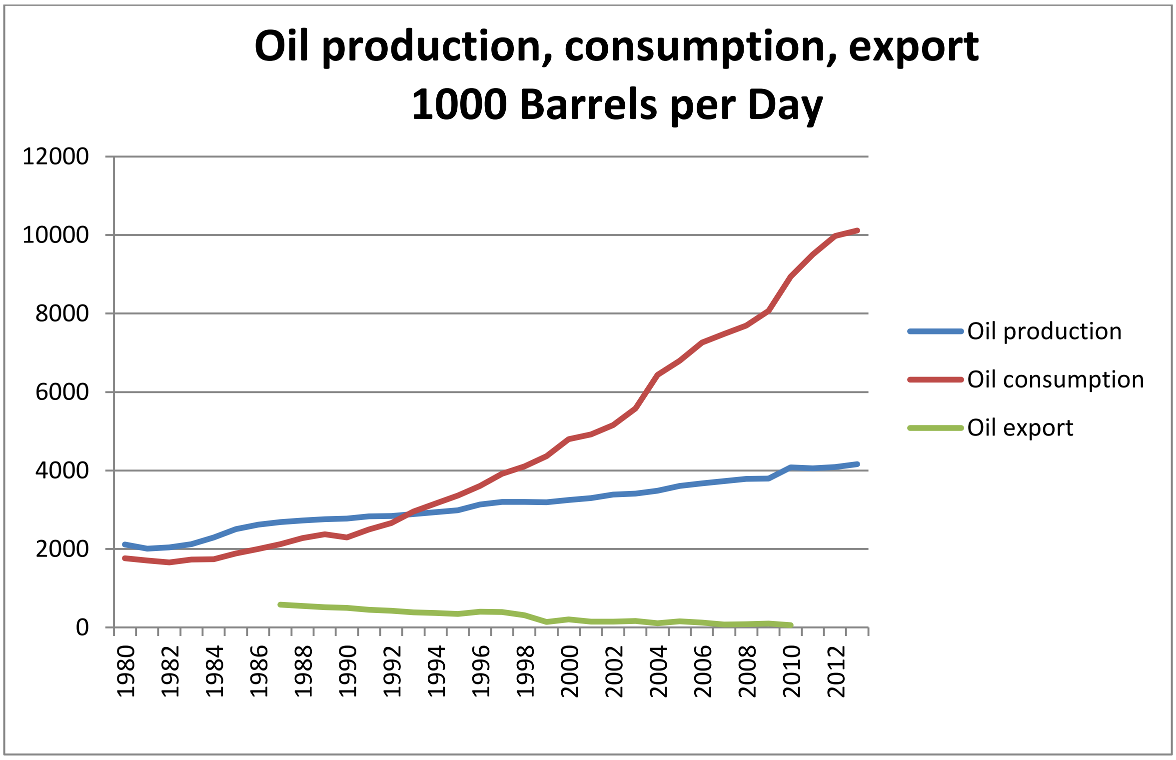

Fig. 6. Oil production, consumption, export; 1000 Barrels per Day (Source: Index Mundi 2016).

As imports are almost negligible, the difference between the production and consumption can be interpreted as imports.

7. Renewable Energy Implementation in China

7.1. Potential Benefits

Renewable energy would bring many advantages and might be the solution to some of the problems of the PRC. In the production of solar and wind energy, no emissions are generated. While it is true that geothermal and biomass energy systems generate emissions to some extent, these are still significantly lower than in the case of coal and natural gas fired power plants. Furthermore, wind and solar energy do not need to use water for energy generation unlike fossil fuel power plants, where considerable amounts of water are used and polluted. The consequence is that neither do wind and solar energy systems pollute water resources nor do they reduce the use of water for drinking water systems or agriculture. (UCS, 2015)

As water scarcity and water and air pollution are severe challenges to the PRC's environment and population, these technologies should be increasingly used as an alternative in China. There are also economic benefits to a shift to renewable energy technologies. While fossil-fuel technologies tend to be mechanized and capital intensive, renewable energy technologies are more labour intensive. Moreover, the growth of the renewable energy sector creates large scale economic effects. As industries in the renewable energy sector benefit and the number of jobs increases, unrelated local businesses will benefit from increased business and household incomes. In addition, people engaging in agriculture can benefit by producing feed stocks for biomass power plants. Furthermore and important in the case of China, renewable energy reduces the dependence on imports of fossil fuels, and keeps, therefore, more money circulating in the national economy. Renewable energy can also be more reliable in terms of energy security. As renewable energy is diverse and spreads out across a large geographical area, a fall out of one system will not cause an electricity fallout for an entire region. Furthermore, renewable energy production is usually composed of different modules in a system. So if for instance one wind turbine is damaged, the rest can continue to operate. Also in the case of extreme weather events, such as droughts or heat waves, renewable energy proves to be more resilient because they do not depend on water for cooling. (UCS, 2015)

7.2.Solar energy:

Solar energy is one of the most important renewable energy technologies nowadays. One can distinguish between four major systems of solar energy utilization. These are solar photovoltaic (PV) power generation, solar thermal electric power generation (concentrated solar power, CSP), solar water heaters, and solar houses. For PV, a decentralised, independent distributed approach used to be the common way for utilization. Only in recent years grid connected PV is becoming more popular. On a global scale, PV will cover a bigger share in the energy mix from a long term perspective. China has also discovered the opportunities offered by PV technology and is making it a key element of its energy strategy of the future. As laid out in According to China's Medium and Long-term Development Plan for Renewable Energy, China's total PV power installation will reach 1.8 GWp by 2020 (which has already been surpassed today), and 1000 GWp by 2050. Furthermore, by 2050 solar PV should account for 5% of the total renewable energy installed capacity. Chinas PV power industry benefits from abundant solar energy resources and supporting policies from the government. (Zhao et al. 2011: 4964)

China has advantageous solar radiation levels when compared to regions in similar latitudes, such as Japan and Europe. More than two thirds of the country has 2000 hours of sunshine per year. However, the various regions of the country located in different latitudes have different amounts of solar irradiations. (Zhao et al. 2013: 230)

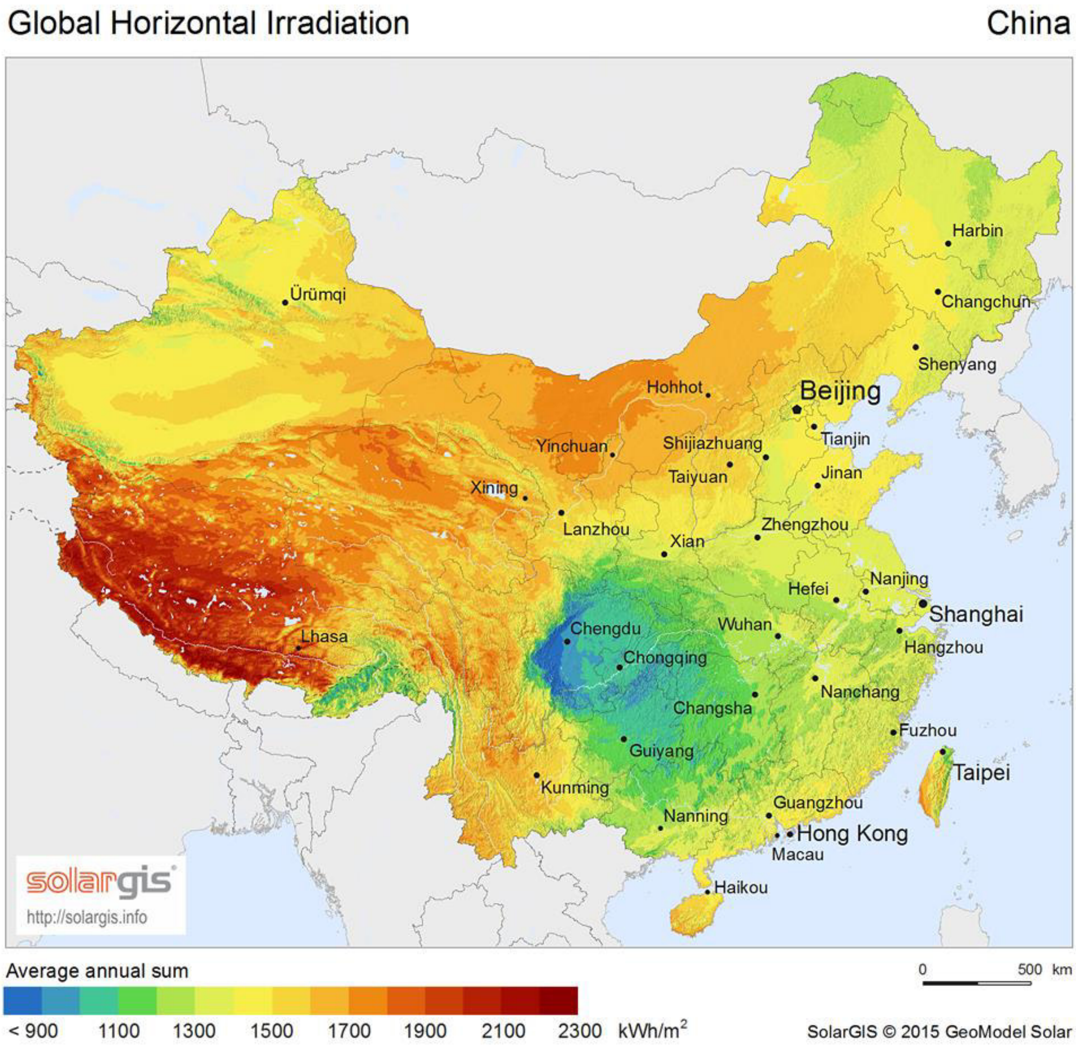

Fig. 7. Global Horizontal Irradiation, China (Source: SolarGIS © 2016 GeoModel Solar)

As can be seen from the solar radiation map (fig. 7), solar radiation is the strongest in the western and northern region and weaker in the south and east of the country. However, wide scale PV installation is not useful in the far west since the Himalayan topography does not allow for big projects. Furthermore, the region is scarcely populated. As a result, the best opportunities for solar power in the PRC are in the southwest and north of the country, where solar irradiance levels range from 1500 to 2000 kWh/m2/year. (IRENA 2014: 50) Unfortunately, this does not correlate with the distribution of the energy demand, as the highest electricity demand in the country is concentrated in the eastern and southern regions, while the solar resource rich western and northern regions consume very little of the demanded electricity. (Zhao et al. 2013: 230) Until now, the greater part of solar capacities is installed in these regions.

However, the PRC plans to expand its photovoltaic energy production in western China. Furthermore, rooftop photovoltaic energy generation will also be increased, mainly in eastern China. Solar water heating is steadfastly increasing in the country even without government support. The PRC is the country of most solar water heaters installed in the world, accounting for around two thirds of systems installed globally. However, the government initiated a programme, which allows subsidies for both rural and urban consumers in China, where the government covers a proportion of the price. (IRENA 2014, p. 41, 50)

China also started ambitious projects in the solar power field. The probably most important one is the Dahan solar thermal power plant, which is the first solar thermal power plant in Asia and is located in a suburb of Beijing. Solar thermal power plants are generating electricity with the help of mirrors that focus the Sun’s rays onto a receiver, while photovoltaic solar panels produce electricity directly from sunlight. (Su et al. 2010: 29)

There are various advantages for the Chinese economy and environment from the use of photovoltaic (PV) technology in China. First of all, as China is aiming to build up a low-carbon economy by using cleaner renewable resources, PV is a useful means to reach this goal, as it does not produce polluting emissions and can effectively reduce the greenhouse effect. (Zhao et al. 2013: 230) In particular regions which are high in solar resources will benefit from the PV power development. Furthermore, increasing fossil fuel prices make PV also economically very attractive in the long term perspective. Moreover, as the energy demand in the country keeps on rising, PV is an important energy source which should be increasingly added to the country’s energy mix. (Zhao et al. 2011: 4966 ff.) Another beneficial side effect of the emerging solar power sector in China is the economic advantage stemming from development of the PV industry. China is nowadays home to a number of leading PV companies as well as research and development centres in the field. (Zhao et al. 2013: 230 ff.) Not only will the PV industry grow from rising internal electricity demand, but also the rising exports of PV equipment will make China an important player in global technology markets. (Yuanyuan 2016)

In 2012 China commanded an installed capacity of 4 GW of Solar PV (utility) and 1.4 GW Solar PV (rooftop). However, the potential for further installations is very high.

The IRENA report of 2014 found that technical potentials for PV installations are as high as 2200 GWe and 500 respectively. (IRENA 2014: 47) Given these numbers and the conductive political and economic circumstances for PV this creates a beneficial environment for the development of the PV industry in the country. Given the total amount of installed energy capacity in China, which amounted to 1370 GW in 2014 the potential from PV is considerable. (China Statistical Yearbook 2015) Already in 2016, this capacity reached 43 GW, surpassing Germany. (Hill 2016)

In the solar power sector, there were subsidy systems introduced from 2009 onwards in order to promote its growth and development. Particularly important to mention here is the "Golden Sun" pilot project: 50 percent of the total investments into photovoltaic projects and the transmission and distributions systems linked to those are subsidized by the Chinese government under this project. Furthermore, subsidies can also amount to as much as 70 percent in the case of independent photovoltaic power generating systems, which are located in remote regions that have no power supply. It should be pointed out, however, that the solar projects have to meet certain requirements before subsidies can be granted to them. One of these criteria is a minimum generating capacity of 300 kW peak. Also the projects have to be realized in one year and be operative for a minimum of 20 years. In order to ensure equal development of solar power in all regions of the PRC, the country's government has limited the maximum amount of solar energy generated by subsidized solar power projects to 20 MW for each province. (Su et al. 2010: 28-30)

Recently there are signs that the government will step back and allow less interference by the state in the solar industry. Stimulated primarily by European market demand, the Chinese photovoltaic cell industry exploded from 2004 onwards and China became the world's largest PV manufacturer in 2007. In 2010, the total production capacity reached 10 GW, which accounted for 45 % of global volume. Since 2011, anti-dumping measures from the United States and the European Union lead to the closure of one third of Chinese PV manufacturers, amongst them Sun-Tech Power in 2013, back then the largest company. By letting this happen and no action taken from the government, it can be assumed that the government has decided that the PV industry is mature enough to let market mechanisms play a bigger role. (Wang 2014: 212-213)

In the case of solar power, China is on a good track, supporting the development of solar power politically and also economically. Given the great technical capacity and the abundance of solar resources, however, efforts should be even extended and stronger state action initiated, to further stimulate the growth of the solar power sector.

7.3. Wind power

Wind power, like solar power, is one of the leading sources of energy from renewable sources and offers great potential for the reduction of CO_2 emissions. Wind power has become more and more attractive for the Chinese leadership in the past decades. Besides being more environment friendly than fossil fuels, it has some advantages to other renewable technologies and nuclear power: wind power is much safer than nuclear power, development costs are cheaper than for solar energy and it emits no pollutants unlike biomass. (Chen 2011: 5013)

Onshore wind power

The most common available wind turbines for electricity generation are horizontal axis upwind turbines with three blades. Horizontal axis describes the axis the blades rotate around. Upwind turbine refers to the fact that the wind meets the blades before it reaches the tower. The most important performance indicator when generating electricity from wind is the cost of energy (CoE). This indicator describes how much each kWh of electricity generated by the wind turbine costs. The CoE includes all kinds of expenses for the production of the kWh and accounts for the cost of installation (CAPEX), the cost of operation (OPEX) and the total energy produced in the course of the lifetime of the wind turbine. As a result, usually CAPEX and OPEX are annualized over the projected lifetime of a turbine and then divided by the projected annual energy production:

$$CoE\ (Cost\ of\ Energy) = \frac{Annualised\ CAPEX\ and\ OPEX}{Annualised\ energy\ production}$$

Annual energy production can be estimated by taking potential full production in utilization hours (T_{util}). So, for good wind conditions typically T_{util} is assumed to be 3000 hours. (Jensen and Undeland 2014: 139 f.) This means a very powerful turbine with 8 MW could produce 24.000 MWh of energy over the course of a year. CoE is the major driver in the wind industry. As one can also derive from CoE not only costs, but also reliability and energy capture, it plays an important role in driving innovation in the wind sector. (Jensen and Undeland 2014: 139-141)

Generally speaking, wind resources for offshore wind farms are better, with wind being steadier and reaching higher speed levels than onshore wind. It should be pointed out, however, that installation costs (CAPEX) and operation costs (OPEX) are significantly higher for offshore than for onshore wind farms. Therefore, this also leads to an overall higher CoE. When the installation costs of an offshore wind farm are examined regarding their individual parts, then the wind turbine itself already makes up one third of the total budget. Therefore, the trend is nowadays to install fewer, but larger wind turbines instead of a high number of smaller ones. So, in an effort to reduce costs of energy from offshore wind turbines, this has led to the development of very large turbines. (Jensen and Undeland 2014: 140-141)

Electricity is generated from wind turbines by converting the rotational movement of the wind turbine rotor to electricity in the generator. The electricity is then fed into the grid at the desired frequency, while the frequency of the electricity from the generator is proportional to its rotational speed which is in turn again a function of the wind speed. However, as wind speeds are unstable by nature, the power delivered from a wind turbine is also unstable. As long as the portion of power coming from wind turbines is relatively small, unstable supply from wind turbines can be absorbed in the power system. Unfortunately, with increasing integration of wind power it becomes more difficult to ensure stability in the power system, which consequently affects the delivery to customers. (Jensen and Undeland 2014: 144)

Considering the CoE wind turbines are usually installed onshore if this is possible, because this means lower CoE. (Jensen and Undeland 2014: 155) This is especially true for China, where only very limited activity in the offshore wind sector can be observed. Furthermore, in China it is much easier to obtain planning permissions onshore than this is the case in Europe, where offshore wind farms are becoming increasingly popular for this reason. However, China could profit from the recent research and development activities done in Europe in this field. Offshore wind turbines have become larger over the years and more energy-efficient and reliable systems have been employed. Today, there is a strong focus on reducing CAPEX with the reduction of production and installation costs. While production costs are being reduced by implementing mass-production methods from other industries, installation costs are being kept increasingly low by employing dedicated installation equipment that is solely designed for the purpose of facilitating the installation of offshore wind turbines. Furthermore, CoE is also an incentive for manufacturers to invest in research and production of reliable and fault tolerant components. (Jensen and Undeland 2014: 155) Since in China investors receive economic incentives for the implementation of wind projects, it is justifiable to assume that this also contributed to the development of inefficient wind turbine models, as the CAPEX and/or OPEX (and consequently the CoE) is lowered.

China's wind power sector has seen a rapid increase since the government's first efforts in this area in 1986, when the first pilot onshore project for wind power was launched in Shandong Province in eastern China. (Chen 2011: 5013-5014) When China reached an installed wind power capacity of 44.7 GW in 2010, it became the world's biggest wind power generator, surpassing the United States. (Lo and Wu 2015: 59) In 2015, China commanded an installed capacity of more than 145 GW. (GWEC 2015) In the same year, it generated 186.3 terawatt hours from wind energy, making up 3.3 % of the country's total energy production. (Xinhua 2016) This made China a global market leader in the wind industry, despite the fact that overall investment declined at the end of 2013. China has overall very good natural conditions for the generation of wind energy. The technical potential for onshore wind energy amounts to a capacity of 1000 GW per year. However, usable wind resources for power generation are unevenly distributed in the country. The best wind resources can be found in northern China in the provinces of Inner Mongolia, Jilin and Xinjiang and in some coastal parts in the eastern region of the country, while the potential in the southern and central regions is rather limited. The occurrence of favourable wind conditions also correlates with the installations of wind farms. Almost a quarter of China's installed capacity of wind energy is found in Inner Mongolia. The rapid increase in wind farms in China can be attributed to economic incentives offered by the government as a result of the renewable energy law of 2005 but also market mechanisms such as government financial assistance, easy and inexpensive transmission access, wind energy cost decline, and a high feed-in-tariff. Furthermore, the governmental political and regulatory support, coupled with low labour and manufacturing costs not only fuelled a rapid growth in wind power generation, but also had positive effects on the development of related businesses in China: Chinese enterprises accounted for 4 of the world's top 10 wind turbine manufacturers in 2015, namely, Sinovel, Goldwind, Dongfang, and United Power. However, the major developers for wind projects in the country still remain mostly state-owned companies. (Lo and Wu 2015: 58)

The downside of the rapid growth of the wind power industry, which was not even expected by the Chinese leadership in such dimensions, is that the wind power sector is now confronted with several challenges. As much as 30 % of installed wind power capacity is left to lie idle, which can be seen as the result of over investment. (Lo and Wu 2015: 59) Lo and Wu find three reasons for this unfavourable outcome:

Firstly, the success of the local or central government official is not measured by energy production but merely by installed capacity. Furthermore, the implementation of wind power projects is mainly controlled by local governments. Local governments may authorize the wind projects below 50 MW after putting them on record with the government body NDRC. Wind projects, which are over 50 MW are authorised solely by the NDRC and managed by it. As a consequence, the problem arises that since local governments can approve projects more easily and more quickly than the NDRC, some wind farm operators simply break down their projects into separate stages, of which each is smaller than 50 MW. Furthermore, wind projects, which were authorised by local governments are not included in the national grid-access plan. This also contributes to the effect that grid and wind farms do not develop in a balanced manner. As a result of these developments, China's National Energy Bureau (NEB) has drafted new regulations in 2011 to standardize the examination and approval of wind projects, which are below 50 MW. The draft states that wind projects below 50 MW must be approved by the NEB, before local governments may authorise them. The government wants to achieve better monitoring of the development process with this measure. As a result, growth in newly increased capacity declined in the years after the draft. (Lo and Wu 2015: 59)

Secondly, despite the fact that China has very good natural wind resources for power generation, wind farms have grown out of balance with the growth of the electricity grid. This led to a large share of the wind-turbine generated electricity being wasted. Power grid construction is significantly behind the growth of wind farms: in 2009 only 62 % of wind power was connected to the grid; in 2011 this number improved to 73.4 %. Moreover, there are discrepancies in the distribution of wind resources and energy demand in the country. While most of wind power is developed in the northern regions, due to the abundant wind resources there, the main areas of electricity consumption are the south-eastern coastal regions. Transformer losses can be directly affected by long distances, which lead to losses of power in long-distance transmission. The low level efficiency of wind farms in China may, to a certain extent, be caused by the site selection. (Lo and Wu 2015: 59)

Thirdly, many of the wind farms in China operate at a low level of efficiency, which is attributable to the use of domestically produced wind turbines that lack reliability. Since the ''Renewable Energy Law of the People's Republic of China'' requires 70 % of the components of wind turbines to be domestically produced, the market share of domestically wind turbines grew rapidly. This led many wind turbine manufacturers to rapidly switch from the prototype to mass-production phase. The result was low electricity production of the turbines. Only with the 2010 "Amendments to Renewable Energy Law of the People's Republic of China," more emphasis was put on actual electricity generation and regulation. (Lo and Wu 2015: 59)

Offshore Wind Power

In recent years offshore wind energy production is starting to gain more attention in China. The benefits of offshore wind farms in comparison to its onshore counterparts are that they do not occupy large land resources. In the specific case of China offshore has significant potential due to Chinas long coastline. (See fig. 8.) Furthermore, as the coastal regions have the highest electricity demand of the country, long distance electricity transmission from western China can be avoided and the electricity produced where it is most needed. Technical and potential offshore wind power capacity amounts to 750 GW in coastal China. (Chen 2011: 5013-5014) Although offshore wind parks should be an attractive option to fight the meet the high electricity demand in coastal China, there are currently only a few projects in the PRC in this area of wind energy. (IRENA 2014, p. 75)

Clearly China has taken extensive efforts expand its wind power industry. It remains disputable as to how far this rapid increase in wind farms was a result of economic considerations or environmental concern. In any case, it becomes clear that the wind energy projects have been implemented in a highly inefficient way, due to lack of coordination and monitoring. At the sometime offshore wind energy, having a high potential and local importance, has been neglected for too long and should be more promoted by the government, both financially and relatively.

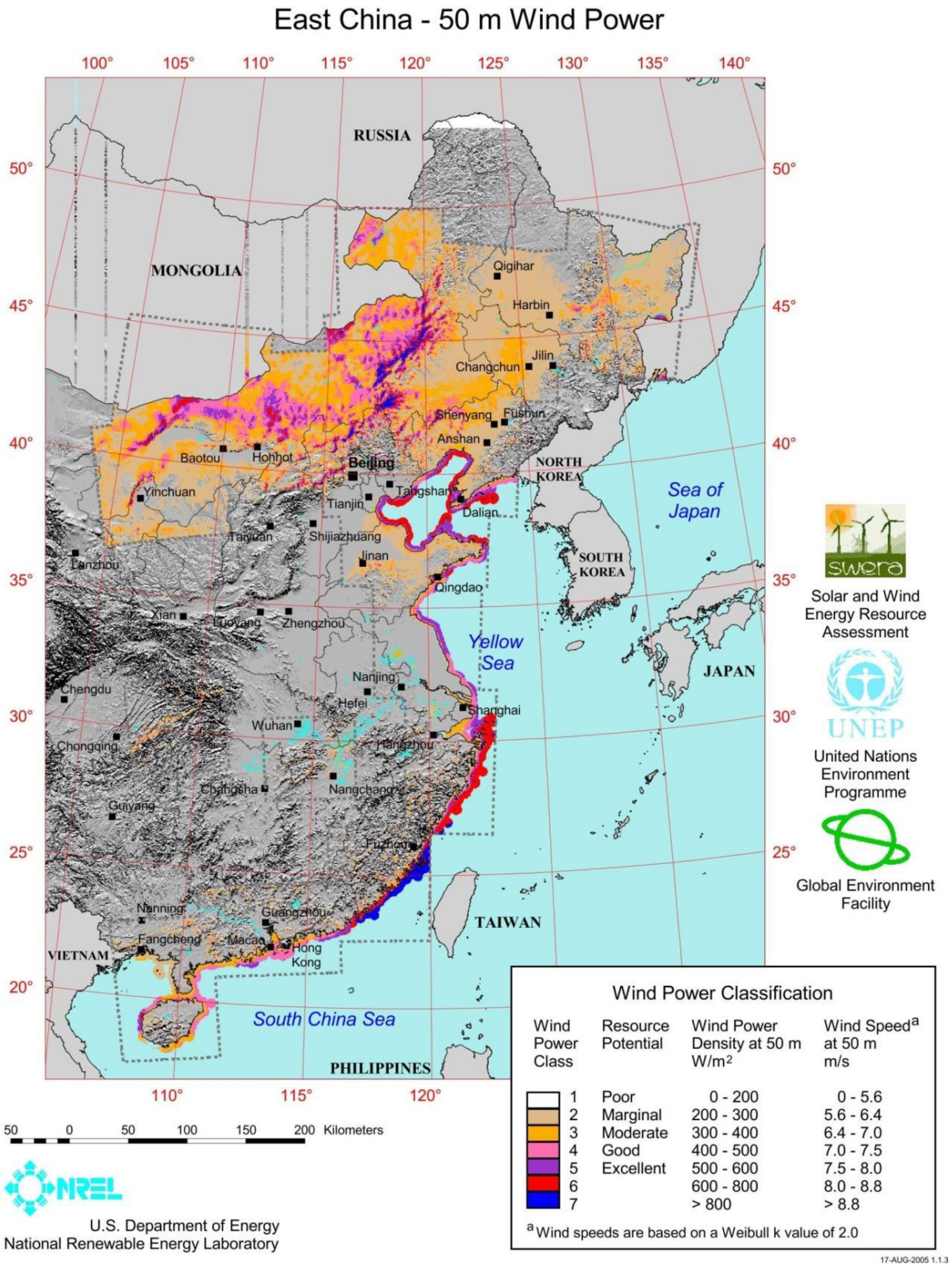

Fig. 8. East China 50m Wind Power (Source: National Renewable Energy Laboratory 2014, remarks: 50m wind power refers to wind in 50m height above ground)

7.4.Biomass

Bioenergy has not yet gained much popularity among the Chinese leadership as a potential source for large-scale public energy generation. However, bioenergy is being traditionally used in the rural areas of the country. There, traditional bioenergy usage, mainly through combustion of crop residue and fuelwood for cooking is still the major source of energy. (Sang and Zhu 2010: 79-80) It should be noted that although the number is gradually decreasing in 2014, still 46 % of the population lived in rural areas. (World Bank e 2016) China has significant biomass resources, however, only a small portion of these are effectively used nowadays. The resources as primarily composed of agricultural and forest logging residues, animal waste and industrial and municipal biodegradable wastes. Straw resources are concentrated in the northeast and lower part of the Yangtse River, while big amounts of wood resources can be found in north-eastern and south-eastern part of the country. The production of straw amounts to around 700 Million tonnes per year in China and is composed of 37 % corn straw, 28 % rice straw and 20 % wheat straw and 15 % straw from various other crops. Approximately 50 % of the straw is used for fodder and fertiliser. That means that around 350 Million tonnes straw are available for energy generation per year of which 40 % are already being utilized. The livestock industry produces up to 170 Million tonnes of animal wastes per year which could be utilised for bioenergy. Different crops for bioenergy have potential to be grown in the various regions of China such as sweet potato, sweet sorghum and cassava. As China has limited forest resources, it has to import much of the forest products. Hence, in the case of forest residues the country has to rely on residues from imported forest products. In total it is assumed that China has a biomass supply potential between 8 - 15.9 Exajoule per year. Translated into power this would amount to 2222 TWh to 44167 TWh per year. (IRENA 2014: 47) However, the slow progress in the elaboration of bioenergy roadmaps and planning in China is explained by the perception of the leadership that substantial bioenergy production requires sizable arable land, which China does not have because of the need to feed its large population. Furthermore, there is substantial lack of research on dedicated new energy crops in China. As a result there is less enthusiasm for bioenergy than for other renewable energy technologies in the country. (Sang and Zhu 2010: 79-80)

Studies of Sang and Zhu found several important aspects with regards to the future potential of bioenergy in China. Firstly, China has the advantage that it possesses a very diverse genetic resource, such as the Miscanthus species, for the development of new energy crops. Secondly, while it is true that China has only small amounts of arable land apart from what is already needed to ensure food security, it has huge areas of marginal and degraded land which is seriously threatened by desertification. Therefore, developing dedicated perennial energy crops on the nonarable land would offer an attractive opportunity. With this solution both environmental and energy problems in the country could be addressed. (Sang and Zhu 2010: 79-80)

Energy crops, which are used to produce renewable energy, can be subdivided into two major categories, namely first and second generation energy crops. First generation energy crops are conventional food and oil crops. From the former sugar or starch from grains is converted into bioethanol and from the latter seed oil is converted into biodiesel. The primary sources for bioethanol today are maize and sugarcane and for biodiesel soybean and rapeseed. In many countries cost-effective bio-refinery technologies lead to the fact that biodiesel is already added as a portion in liquid petroleum for transportation. The downside of first generation energy crops is, however, that they have an impact on the environment and might also affect food security. As these crops are cultivated for human food supply, utilizing them for biofuel production may lead to shortages of food. So, in order to grow additional crops for biofuels, additional farmland has to be converted from natural ecosystems, which leads to deforestation, soil erosion and loss of biodiversity. Furthermore, when productive natural ecosystems are converted into farmland their function as natural carbon sinks is lost and on top of that carbon stored in the ecosystem is released. Moreover, the growing of grain or oil crops demands a high-energy input in tillage, planting, weed control, fertilization and irrigation, which lead to a relatively low net energy gain from first generation energy crops. Sugarcane has a better net energy gain when compared to the other first generation energy crops. However, it only grows in tropical regions, where the ecological value of natural vegetation is especially high. As a consequence, substituting fossil fuels with first generation energy crops is not a sustainable option combat energy shortages and environmental problems, such as climate change. Chinese efforts in the bioethanol and biodiesel production backfired in the mid-2000s: although the production of these fuels was largely extended, while the extra arable land in the country is already scarce, it could still only replace a small fraction of the gasoline used by the country. Moreover, and more importantly, the increasing biofuel production, competing with food crops for land and irrigation, also significantly contributed to driving food price increases and turning China into a net grain importer. Therefore, primary food crops are not to be considered as a future source for the development of renewable energy in China. (Sang and Zhu 2010: 80-81)

Second generation crops on the other hand are dedicated crops which have the ability of growing in marginal land which cannot be used for food production. These crops are perennial plants with high water and nutrient use efficiency that yield high annual biomass production. As they are grown on land, which has low natural productivity, land use changes do not lead to GHG emissions. On the contrary, land use changes in this way may lead to additional soil carbon accumulation. Therefore, these two features combined lead to a high net energy output and no CO_2 emission from the growing of these crops. Among the flowering plants that are considered to be the most promising candidates for second-generation energy crops in different parts of the world are perennial grasses such as Miscanthus, switchgrass, short rotation coppices (SRC) and the oil-producing shrub, Jatropha. The first four plants listed above, also named lignocellulosic energy crops, are quickly growing grasses or trees, with high biomass yield in the form of cellulose, semi-cellulose, and lignin. Jatropha yield nuts rich in oil, suitable for biodiesel production. Lignocellulosic crops provide a more efficient biomass yield because the entire aboveground plant is harvested as biomass feedstock unlike in the case of Jathropa where just the fruit is harvested. Furthermore, they also grow in a wider climatic spectrum, which makes it suitable for a larger area of marginal land. The energy from lignocellulosic crops is converted into ethanol by cellulose through cellulase digestion followed by fermentation. However, particularly the step of enzyme digestion is still relatively expensive. As another option biomass can be combusted alone or in combination with coal in order to generate electricity. Moreover, energy conversion efficiency is estimated to be higher when lignocellulosic crops are used as feedstock for generating electricity than for producing ethanol. Furthermore, in order to enable the combustion of biomass at an existing coal fired power plant only moderate technical modification is needed. (Sang and Zhu 2010: 81-82)

It can be concluded that although bioenergy from crop residue could replace tens of million tons of coal and power generated by the fossil fuel, however, its agro-ecological role in erosion control, carbon sequestration and soil conservation should be given priority. As a result the bioenergy gained from the remaining crop residue would make up only a few percent of total energy production. Bioethanol and biodiesel produced from energy crops does have the potential to increasingly replace a fraction of petroleum for transportation. However, this potential is limited by the scarce land in China. (Sang and Zhu 2010: 83-84)

For the case of China, the 14 Miscanthus species, which can be found throughout Asia, seem to be the most promising option for several reasons. First, China is home to many high biomass Miscanthus species across most of its climatic zones, which offers a great opportunity for crop domestication and improvement. Secondly, studies in the United States and Europe have found that Miscanthus species have higher biomass output, higher land-use and nutrient efficiency and better net energy production than other lignocellulosic species. (Sang and Zhu 2010: 82) Considering the specific case of China, where water, land and nutrients might be limiting factors for energy crop production, the Miscanthus is most likely the best suitable energy crop.

From the environmental perspective, there are also several advantages from the Miscanthus species specifically: One third of China's northern grassland has suffered from different degrees of degradation. Reasons for this were overgrazing and land use change for crop production and fuel production. As a result this land suffers from severe reduction of productivity, loss of organic matter from soil and the emission of GHGs. Grassland, which is degraded to a high level, is becoming a victim of desertification at rate of a quarter Million hectares per year. However, extensive research on grassland restoration and desertification prevention in northern China has shown that the reduction of grazing and the planting of herbaceous perennials, such as Miscanthus, are the most effective measures, which lead to restoration of degraded grassland. Miscanthus, which is home in these areas, could therefore also play a highly important ecological role. Furthermore, erosion and loose soil in central and north-western China has led to loss of natural vegetation cover, landscape degradation, soil nutrient depletion, sandstorms and excessive sedimentation in the Yellow River due to human activities and climate change. The Chinese government already is engaged in promoting and subsidizing land restoration of low productivity cropland and pasture to forest or grassland in the region. The Miscanthus species is in this case not only of ecological but also economic importance: Studies have shown that land improves from the growth of perennials, as a result of rapid accumulation of soil organic carbon and improvement of soil structure and function. Therefore, the growth of perennials can support natural vegetation restoration, restore soil fertility, improve land productivity and consequently enable land rotation for food production. (Sang and Zhu 2010: 84-85)

With regard to absolute numbers for CO_2 emission and energy production Sang and Zhu calculated that China should have over 100 million hectares potentially available for growing Miscanthus crops. With an average yield of 10 t dry biomass per hectare^{-1}, this would mean that a total of 1 billion tons can be harvested annually as bioenergy feedstock. They further calculated that this could produce around 1458 TWh electricity and mitigate 455 million tons of carbon or 1,7 billion tons of CO_2 emission from coal. These numbers already include soil carbon sequestration. (Sang and Zhu 2010: 85-86) Electricity produced as such would account for 25 % of electricity demand and reduce the countries GHG emission by 10 %.

7.5.Geothermal energy

Being a nearly pollution free renewable energy source, geothermal energy has gained more attention from the Chinese leadership and enterprises recently as it could help easing the current pressure on energy supply and contribute to the improvement of the environment in the country. The geothermal resources in China are abundant. (Zhao et al. 2014: 652) In geological terms, China covers the south-eastern corner of the Eurasian Tectonic Plate, while it is being influenced by both the Indian Australian plate from the south and the pacific plate from the east. The junction of these plates led to the formation of two geothermal belts: The Himalayan Geothermal belt, which is 150 km wide and 2000 km long, extends from southern Tibet down to through the southern provinces and further passes to Thailand. The Circum Pacific Belt extends along the coast of eastern Taiwan. (Prebble and Prebble 2012) The majority of geothermal resources in China are low to medium temperature type resources; it is estimated that 8 % of total global geothermal resources can be found within the borders of the country. However, the distribution of the resources is not even. (Zhao et al. 2014 652) High temperature resources are to be found in the regions of the geothermal belts: Tibet and the southern provinces, western Sichuan and Yunnan, are active tectonic zones, with around 170 known geothermal systems. (Prebble and Prebble 2012) Low to medium temperature geothermal resources are primarily found in the southeastern coastal area and in northern and northeast China. (Zhao et al. 2014 652)

The use of geothermal resources has a relatively long tradition in China, which started to make use of its hot spring already in the 1970s, as a reaction to the global oil crisis, making it one of the world's first users of this type of energy. Later in the 1990s China's geothermal energy development and utilization have been rapidly growing, mainly driven by market demand. Today China's geothermal energy is primarily used for power generation and direct utilization which includes heating and cooling, spa treatment, agricultural use, industrial production, etc. Furthermore, as the utilization of shallow geothermal energy is hardly restricted by resource distribution, it could develop quickly and technologies became increasingly mature. Geothermal power generation can be divided into two systems: conventional power generation and enhanced geothermal systems (EGS) power generation. Conventional type systems are subdivided into high temperature, which means above 150 degrees Celsius and low-medium temperature geothermal power generation. The conventional systems are being used since a long time in China and therefore stand on a solid technical foundation. EGS power generation on the other hand is still in the phase of project research and development. Research found that geothermal power generation is much more cost-effective than direct geothermal use, with utilization coefficients of 73 % and 23 % respectively. (Zhao et al. 2014 652-653)

Conventional power generation systems: Currently the Chinese total high and quasi high temperature potential is known to be 5817 MW. Since the 1970s China began to apply this type of high temperature geothermal power generation. Power plants were successfully established in Tibet, Lnagjiu and Naqu. Furthermore, a few low-medium geothermal power plants were built across the whole country, but some of them were closed down again. Recently, especially the low-medium temperature geothermal power generation is experiencing a comeback. Particularly in the deep both large and medium sedimentary basins coexisted with oil and gas fields. A lot of these low-medium geothermal resources are available for exploitation and utilization. (Zhao et al. 2014 653-654)

Enhanced geothermal systems: The advantages of EGS power generation are the huge deposits, high efficiency, stable system structure and little negative effect on the environment. Deep geothermal energy can be exploited from low permeability rock mass at depths of 3-10 km underground. Nowadays this technology is the standard for geothermal energy generation worldwide. Furthermore, the utilization of EGS is rather economical. The investment costs for EGS power generation are comparable to wind power and considerably lower than for solar power. Moreover, it is predicted that the cost for geothermal drilling will decrease, as this phase of the energy extraction will benefit from developments in the oil drilling industry. Furthermore, it has been found that core technologies from shale gas extraction such as horizontal well technology, fracturing technology can be directly transferred to geothermal resource development. Zhao predicts that once geothermal energy reaches a wider utilization, its application will be much more competitive than solar and wind energy. Despite these favourable circumstances, however, research and development in the geothermal sector has been lagging behind in China for decades. There has been no technology research base formed in China and input on the international level mainly consisted of academic exchanges. However, in recent years China has significantly enhanced exploration and project investment. With the support from the government and the progress made in projects there is increasingly more technology accumulation and growing potential for development. (Zhao et al. 2014: 654)

It can be concluded that although China has a lot of geothermal resources at disposal, it only uses them through direct use, which is rather inefficient. There is a strong need to enhance research and development in this field through financial incentives similar to the solar and wind sector. Particularly enhanced geothermal systems should be a top priority for the Chinese leadership and local governments.

7.6. Hydropower

Although hydropower does not cause any GHG emissions during immediate electricity generation and operation, it does have numerous negative effects on the environment, which are often underestimated:

1. Changing water levels and erosion

   In the case of storage projects, reservoirs (lakes) are built, which can raise the water level behind a dam up to several hundred meters. This leads to inundation of stream banks and riparian areas. As a result, entire habitats change, which has an impact on animal species and humans. (FWEE 2016) Changing water levels also lead to erosion, by cutting deeply into the banks of the river. In the case of the Three Gorges Dam already over a million people had to be moved from their homes, due to the rising water level and the increasing threat of landslides resulting from it. (Zeit Online 2010)

2. Sedimentation

Sediments consisting of fine organic and inorganic materials, which are usually suspended in the water, will collect behind a dam. This leads to two very opposite effects on the river: the downstream part of the river, can suffer from decreased nutrient supply because the important sediments do not reach the river after the dam anymore. At the same time, before the dam the upstream part of the river is affected. Because of the accumulation of sediments, an effect called “nutrient loading” causes the depletion of oxygen: As there are more nutrients available now, organisms start to increasingly spread in the area and consume them. However, during this process also oxygen is used, depleting the O_2 supply in the reservoir. (FWEE 2016)

3. Habitat changes for fish and wildlife

Hydroelectric power stations affect the migration of fish to their breeding grounds, which is vital for the survival of certain fish species. Not only the dam as a physical barrier impairs fish mitigation, which can be overcome by fish ladders, but also changing water speeds, which affect the orientation of fish. Furthermore, the ecological habitat for fish is altered in general as a result of erosion, sedimentation, temperature changes and decrease of oxygen levels. Moreover, inundation resulting from hydroelectric projects leads to the loss of critical habitats for wildlife such as birds, waterfowl, and small and large mammals. (FWEE 2016)

Traditionally, hydropower has played an important role in energy generation in the PRC. The Chinese government strongly promotes future hydroelectric development in the country. With inhabiting about half of the world’s total number of dams it ranks first in quantity of those. Alone in 2012 China’s hydropower sector generated 864 TWh of electricity, which amounted to one fifth of the world’s total. In accordance with the Chinese 12th five year plan (2011-2015) the government has set new goals for non-fossil fuel energy. This should account for 15 % of the total energy consumption by 2020, while more than half of these 15 % should come from hydropower. The new target for hydropower capacity is set to 420 GW by 2020, which will be a 70% increase, compared to 2012. However, the increased utilization of hydropower will increase the pressure on already vulnerable Chinese water resources. At the same time water requirement for food production will increase, as a result of socioeconomic developments and the increasing shift of the diet towards water-intensive foods such as meat. (Liu et al. 2015: 1-2) China already uses a great amount of its water resources for electricity generation. Considering the ecological impacts of hydropower described above and the scarcity of water resources in the future, China should refrain of further expanding hydropower, but rather make use of other renewable energy sources. Moreover, it is questionable in how far hydropower is economical, if big numbers of people have to be permanently resettled from their home areas, as was already the case in the past in China.

7.7. Obstacles and Limitations

Although the development of renewable energy is taking place at a high rate in the PRC, there have been identified several limitations and obstacles to effective deployment: One of the great obstacles are weak and incomplete incentives and supervision mechanisms. These are the result of the most critical issues China is facing in the area of renewable energy development: technical and economic challenges. While it is true that renewable energy has profited from technological innovation and has more and more become economically competitive, the technological development of renewables is very fast, but the costs remain relatively high. Different energy authorities introduced subsidies, tax policies, R&D policies and various other measures to promote the development of renewable energy. However, despite the government announcement of establishing a renewable energy development fund in the new version of the Renewable energy law, related supporting policies have not yet been worked out and there is no clarification about the details of the fund. Moreover, with the immense growth in the renewable energy sector investments in R&D and subsidies also increased. However, R&D of renewable energy has mainly been done by government science- and technology projects. The industry has been less involved in this field, because public investments primarily concentrate on R&D involving mainly universities and research institutes. Another reason is the lack of R&D investment instruments on the industry side. Generally China's R&D investment levels in renewable energy are lower than in most developed nations. As a result, the described incentives are probably not enough to position China in the global technological leadership in this field, although there is significant potential for China to take on the leadership in the manufacturing area. (Wang 2014: 214-216)

Further obstacles to successful renewable energy deployment are lack of innovation in the research and development (R&D) area and in regional policy. For maintaining and improving competitiveness of a rising renewable energy industry, basic research and technology development are important pillars. From both the governmental but also the industrial side more attention should be designated to research and technological innovation. With regards to renewable energy China has only recently established an industry system through introducing, absorbing and assimilating technologies from abroad. That means that most of the core technologies are imported. However, Yang points out that independent innovation, technology upgrading and talent-grooming are crucial to the industry. The state and the industry must both increase their R&D contribution to renewable energy in order to improve the overall technological levels in the sector. Moreover, measures and tools which are designed to promote the development of renewable energy, have still to be adjusted to local conditions. For instance, they have to be brought in line with existing regional renewable energy policies. However, the state in China still focuses on macro-policy instructions, which are to be applied nationwide. As there are big differences between the various regions in China, the macro policies introduced by the state are not applicable in the same way for each region. As a result the government should strengthen and extend the regulatory capabilities of provincial authorities. Furthermore, it should refrain from implementing nationwide polices, but rather pursue policies, which tailor different measures for the various regions. These policies would then be in line with local conditions. (Wang 2014: 215-216)

Another problem in the implementation of renewable energy is the lack of policy coordination and consistency. Responsibility for renewable energy business is divided across a number of sectors in China. This makes it very difficult to have a consistent energy policy. Despite existing regulation in the renewable energy law that tries to harmonise the integration of provincial targets and plans with the national strategy, there are still projects, which try to avoid the complex approval process at national level by “cheating”. This is especially done in the case of wind projects: As has been described earlier many wind projects set their capacity scale below 50 MW in order to avoid the difficult and long approval process by the NDRC. The results were somewhat irrational development patterns for wind resources in China and increase in unused wind power capacity. As an example, a fraction of the electricity generated by wind in Inner Mongolia has to be transferred to the grid of North China, because the local consumption capacity in Inner Mongolia is limited. However, with the construction of the HeBei wind power plants the north China grid has not enough room anymore to feed in more electricity from Inner Mongolia. This then further undermines the market for wind power in Inner Mongolia. (Wang 2014: 214)

Problems also arose from conflicts between renewable power generation and grid companies. In a centralised system grid access is crucial for the commercial success of renewable energy generation. As electrical system operation and management have to a large extent concentrated on large electrical generating sources and large grids, they are therefore not well-suited for integrating renewable but intermittent power systems. With the growing rate of renewable energy development, the challenge for power-system operation has even increased. Also in this case particularly wind energy scores badly in comparison to other renewable energy system. For example, the state electricity regulatory commission (SERC) issued a report in 2011, according to which a total of 2,800 GWh of electricity generated by wind went unpurchased during the first 2 quartals of 2010. (Wang 2014: 215-2015)

Wang defines the following reasons for such developments:

- First, although the government defines the purchasing relationship between power generation companies and grid enterprises, there is still a lack of regulating methods for the implementation the mandatory quotas of renewable energy carriage for power-grid companies set by the government. (Wang 2014: 215)
- Secondly, there still are no effective, powerful and transparent supervision instruments in place. While it is true that the energy authorities have declared that grid companies are obliged to purchase all electricity produced by renewable energy facilities, these efforts will remain meaningless as long as the lack of regulation is not resolved. A major problem is that grid companies do not have to fear punishment if they do not succeed to fulfil their mandatory obligations. (Wang 2014: 215)

- Third, there is a mismatch between wind power and other power resources in North-eastern China, which also limits the access of wind power to the grid. A large part of the co-generation facilities in north-eastern China is used to supply both electricity and heat in the winter season. The problem with these units is that they generally do not have peaking capacity, which means that they have to be operated at 100 per cent of capacity. At the same time middle and small thermal power units with peaking capacity have been gradually shut down. Therefore, in order to guarantee electricity network stability and the heating supply of residents grid managers have restricted the access of wind power to the grid. (Wang 2014: 215)
- Furthermore, there are also difficulties of feeding renewable power to the grid because of the high installation costs. These have made grid enterprises very reluctant to connect wind power to the main grid network, despite their obligation to do so under the renewable energy law. (Wang 2014: 216)

In the 12th Five Year Plan for economic and social development of the republic of China the country has recognised the difficulties, which are faced by the wind power sector. Accordingly, it proposes the construction of enhanced grid-connection support projects in order to promote the more efficient development and utilization of wind power. (Wang 2014: 217) Considering the big wind power capacity in China and the huge amount, which is running idle, the development of efficient grid connection should be a pressing agenda.

8. Decentralised energy

Distributed generation or decentralised energy is a way of producing energy by using small-scale technologies in order to generate the electricity close to the end consumer. (Distributed Generation 2016) Distributed energy systems (DES) are becoming in recent years an increasingly attractive option for power generation worldwide. Reasons for this are the high overall efficiency, low greenhouse gas (GHG) emissions, high reliability, cost saving of grid construction and shortened transport distances of DES systems. (Han 2016: 288 - 289) As a result, these characteristics lead to the generation of overall lower-cost electricity and fewer environmental implications. In the traditional electric power generation paradigm (centralized) usually the supply is provided by a few large-scale generating sources, which can be located far from the load centres. A main disadvantage of centralized power generation systems is that long transmission distances lead to inefficiencies and power losses over the transmission lines, which in turn has implication for the security and environmental sustainability of power generation. (Distributed Generation 2016)

In contrast to this, distributed generation utilizes many, but smaller scale generating plants close to the load centres, which significantly lessens their dependence on the distribution and transmission grid. Furthermore, transmission issues, due to long distances are eradicated. The units that produce energy under the DES can stand alone or be integrated into the local power grid. So for instance if a private household installs solar panels, it may connect these to the grid, as it is unlikely that it will always use up all of the generated energy. Such a situation is a desirable outcome for both the power grid and the consumer. Distributed energy generation can be broken down into two different levels: the local and end point level. On a local level usually power plants are used, which are specifically attractive for the specific location. Therefore best suitable renewable energy sources can be identified for each site, such as wind, solar, or geothermal energy. On the end point level, consumers, be it private households or industry also have additional applications at the site where the energy is consumed. These are installed to back up the local power grid. (Distributed Generation 2016) Further advantages of DES are the flexible operation mode and the potential to combine electricity, heating and refrigeration technology. (Ming et al. 2015: 1227)

For the specific case of China Ming argues that introducing DES technology is vital for the country, if it wants to reach its energy targets:

> *"Therefore, developing distributed generation is the inevitable Requirement to improve the energy efficiency, and to promote of energy conservation and emissions reduction."* (Ming et al. 2015: 1227)

As DES technology could rely to a significant part on renewable energy in China, such a system would have low pollution emissions and substantially reduce the environmental costs of energy production and economic activities. Furthermore, energy safety would also benefit from such a shift to decentralized systems. In the case of power grid emergencies, which can be caused by natural disasters or unexpected events, DES systems are much less vulnerable, because as power generation is scattered among many different power plants, when single plants are out of service, this does not cause major power disruptions and the local power supply remains relatively stable. This is not the case in centralised systems, where great areas are connected to one central power grid, fuelled by a few plants. If a breakdown occurs in centralised systems, implications in terms of energy safety tend to be much more severe. (Ming et al. 2015: 1227) In China, research and development of DES has started comparatively late. However, as renewable resources are abundant in China and DES technology employs various renewable energy technologies, there is considerable potential for DES in the country. As a result of the great demand and air pollution DES has started to grow rapidly in the recent past. (Han 2016: 289-295) in the PRC the distributed energy generation is primarily focused on the following energy sources: natural gas, photovoltaic, wind power and small hydropower to some extent.

Natural gas

The advantage of DES using natural gas is that it is a very versatile fuel, which can combine cooling, heating and power (CCHP) in a system. The energy utilisation efficiency lies over 70 %. Usually the greatest investors in natural gas DES in China are building owners, who would like to provide their buildings with CCHP technology themselves. The development of distributed energy from natural gas in China can be considered very basic. Today, natural gas distributed energy is mainly being developed in Beijing, Shanghai, Guandong, and Sichuan. Projects in this field are mainly supported by the government in the major cities. Furthermore government enterprises offer training programs and also recent engage in establishing companies for natural gas DES development. (Ming et al. 2015: 1227-1228)

Solar Photovoltaic

Photovoltaic DES are comprised of modules, which convert solar energy into electrical energy. Currently most of the photovoltaic DES in China are PV power generation projects installed on the roofs of building in urban areas. Using rooftop PV has the advantage that no additional scarce space is used up for implementing these projects. Although PV DES started only very recently it showed rapid growth over the last years, due to the continuous support policies implemented by the government. In order to explore the technology, management and operation of distributed PV applications, the National Energy Administration has designated different zones for the construction of such projects for R&D purposes, including 18 parks. In 2014 the total capacity of PV

DES reached 4.67 GW. Although this is still a relatively small proportion of total installed PV capacity (almost 11 %) the growth rate of distributed PV is increasing over-proportionally. This become clear when also the numbers of previous years are examined: While in 2010 the installed capacity amounted to 356 MW it already rose to 2.3 GW in 2012. (Ming et al. 2015: 1228-1229)

Wind power

Wind generation DES make use of wind energy by converting it to mechanical energy and then to electricity. Typically wind energy DES are utilized in a combined generation system (usually combined with solar or fossil fuel power generation). Currently the focus lies on the development of the wind and solar complementary power generation systems. (Ming et al. 2015: 1229-1230) However, the problems in the wind power sector already outlined above, also translate into the wind power DES, with all its negative implications.

Small hydropower

Small hydropower plants in China are defined as having a capacity below 50 MW. These kinds of power plants spread over the whole country also due to government policy support. Until 2015 the extensive efforts have solved electric utilization problems for 300 million people. Current plans and studies showed that there is 128 GW potential capacity for small hydropower plants. The resources are scattered over the whole country, but are primarily concentrated in remote mountainous areas in the west. However, these resources are the most abundant, and have most exploitable quantities, accounting for 62.1 % of the country’s total. (Ming et al. 2015: 1230)

Energy storage

In the case of many of the renewable energy technologies, such as solar, wind and also hydropower to some extent the energy source is not constant but rather fluctuating. For such cases, the power systems must be able to store their energy to overcome these changes in the energy supply. In order to store energy it has to be converted from electrical energy into some different kind of potential energy. The applications used therefore can be batteries, superconducting coils, flywheel and pumped storage. In the case of DES, batteries are very attractive options for energy storage, because they are quiet and do not pollute during operation, which makes them well suitable for suburban areas, close to the load centres. (DG 2016)

Difficulties and Solutions

The main problems from a policy perspective for DES are ever returning inconsistencies in Chinese policy making and implementation. Although there are overall guidelines to pave the way, the understanding of policies is inconsistent across the country and there are no applicable standards for DES implementation. This seriously affects the development of DES and leads to inefficiencies of DES systems. In the specific case for natural gas another major obstacle is also the lack of policies such as international cooperation agreements in order to secure sufficient gas supply for the future development and wider application of the technology. (Ming et al. 2015: 1231) For an efficient implementation of DES systems, it is very important for the Chinese government to introduce technical standards into the DES industry, which should facilitate obtaining long term research results and practical experience. Such standards should include research parameters, indexes, requirements for key equipment and standards linked to design, manufacture, operation, maintenance and inspection of distributed energy systems. Furthermore, technical guides for industrial activities should be developed in the field. Standards will not only ensure the effective development and implementation of growth systems, but would also be an assessment criterion for qualified technology and equipment. With the formulation of technical requirements such as quality indexes for product performance, test methods, inspection rules and so forth, there is a regulating tool, which can determine whether a DES product can obtain market access. (Ming et al. 2015: 1235-1237) Such an out sorting of products in the development process of DES systems, whether they can obtain market access is important in order to ensure products of low quality are not used for DES project implementation, as this would lead to inefficient functioning and further development. High quality products on the other hand fuel the growth of the sector. In addition, distributed energy generation standards should consider the dimensions of resources, environment, natural and grid conditions. As distributed energy will play a vital role in China’s future energy regime Wang suggest to elevate the DES development on a national level, by establishing a designated department responsible for planning, policy formulation and organization of DES systems. (Ming et al. 2015: 1235) The establishment of such a department is ambiguous. On one hand this would mean another state department in the field of energy, following plans exclusively in their scope of duties. Such a development might lead to further inconsistencies, conflicted interests and short-sightedness in the energy sector. An advantage would be that DES deployment is elevated to an equally important position as other energy matters, giving it a stronger base for further growth. On the other hand if decentralised systems are not enjoying the privilege of being backed by a designated department, but are rather dealt with in the NDRC or NEA it can be expected that DES systems will remain holding a subordinate role in energy generation. Here particularly the significance of the powerful state owned energy enterprises should be highlighted, which strongly shape China's energy sector, while pursuing their classical centralised energy paradigm. Another important aspect in the development of distributed energy technologies in China is efficient energy storage. As DES technology is still very infantile in China, storage technologies are still highly dependent on input from other (developed) countries, which in turn will hinder the development of the domestic distributed energy industry. As a consequence, the government should promote technological innovation by funding and other financial incentives and establish a research and knowledge foundation in order to accumulate experience about operation and management of distributed energy systems. (Ming et al. 2015: 1235)

9. Flue gas treatment

9.1. Desulphurisation of flue gas

Thermal power plants produce a considerable amount of pollutants, among them various types of sulphur oxide. For the particular case of coal fired power plants, the situation is that Sulphur in coal cannot be destroyed, but only converted from one form to the other. (Prasad et al. 2016: 328) During the combustion process sulphur reacts with oxygen forming SO_2 and SO_3. Sulphur Dioxide (SO_2) has implications on the environment in various forms the most important ones being acid rain, increased corrosion of metals and health problems.

When SO_2 is emitted to the atmosphere it reacts with oxygen and water forming sulphuric acid:

$$SO_2 + \frac{1}{2} O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

The precipitation of this sulphuric together with rain water as acid rain leads to the following environmental implications:

1. Effects on aquatic ecosystems:
   Healthy freshwater lakes usually have an acidity of about 8, which is slightly basic. The consequences of acid rain on aquatic ecosystems, such as lakes, streams and ponds can be disastrous leading to the loss of sensitive species like macro invertebrates. Furthermore, the ability of fish eggy to develop and hatch might be seriously impaired. Moreover, the loss of plankton and the native aquatic vegetation coupled with the spread of acid-tolerant species of vegetation leads to serious alteration of the ecosystem. (Rosenberg 2015) At an acidity above Ph 5 the fish population is totally exterminated. (Prasad et al. 2016: 328-329)
2. Dissolving of heavy metals
   As acid rain facilitates the dissolving of heavy metals in the earth's crust such as lead and Mercury, (Pb, Hg). These start to accumulate in organisms, particularly in fish. Through the food chain these heavy metals are being passed on up onto human beings, causing health problems and diseases. (Prasad et al. 2016: 328-329)
3. Effects on soil
   Soil Ph is a determining factor for the health of vegetation and the presence of microorganisms in the soil. Furthermore, the Ph of soil also influences the availability of nutrients and plants. When acid rain enters the soil, vital nutrients are leached out of the soil and in the worst case enter aquatic environments through run-off. The increased acidity of the soil also leads to the loss of important soil bacteria, which break down important organic matter. (Rosenberg 2015) As a result acid rain destroys the agricultural potential and the soil fertility. (Prasad et al. 2016: 328-329)

4. Effects on cultural heritage

   Acid rain also has the potential to destroy cultural heritage by leading to corrosion of stone facades or monuments. Particularly marble is vulnerable, which reacts with acid rain to from gypsum. (Rosenberg 2015)

Besides the negative effects of acid rain, SO_2 itself can also lead to severe health issues. Exposure to high levels of SO_2 results in breathing problems, respiratory illnesses, changes in the lung's regeneration ability and exacerbation of respiratory and cardiovascular diseases. The people most sensitive to SO_2 emissions are asthmatics, or chronic lung or heart disease patients. (Prasad et al. 2016: 328-329) Furthermore SO_2 emissions are also one of the major precursors of smog, which can be at times highly toxic and seriously impairs visibility. Especially in China smog poses a serious problem. (Quartz India 2015)

In order to reduce the negative environmental and health effects of sulphur emissions, while at the same time recognizing that China still relies heavily on coal fired power, which is the biggest human made emitter of SO_2, and that this will not change in the short term perspective the application of desulphurisation technology is vital.

Flue gas desulphurisation (FGD) technology first started to be applied in the 1970 in the United States and Japan, and from the 1980s also increasingly in Europe in coal fired power plants and some industrial processes. In principle, in the FGD process the flue gas interacts with an absorbent medium in either an absorber or scrubber vessel, which produces sulphur containing slurry. There are several different methods for FGD. Córdoba points out that a great amount of the specialised literature published in this field comes to the conclusion that wet limestone FGD systems have relatively high desulphurisation performance and at the same time have low operating costs. (Cordoba 2015: 275) As Chinese industry and energy sector cannot afford expensive desulphurisation methods, because of their low cost production model, the wet limestone FGD appears as the most attractive option.

FGD systems are classified as either non regenerable or regenerable, depending on whether the sulphur compounds are separated from the absorbent as a by-product or have to be discharged together with the absorbent as waste. Also in the case of wet FGD this distinction can be made. In the regenerable process the sorbent reagent undergoes a regeneration phase, where SO_2, H_2SO_4 or S and a sludge, which can be sold to offset the cost of operating the FGD system, are produced. In the non-regenerable process the sulphur bounds irreversibly with the sorbent, forming a new substance, which has to be disposed of accordingly. If possible the product can also be used in certain applications. Wet FGD systems used in the field of power generation typically use limestone ($CaCO_3$), slaked lime ($Ca(OH)_2$), or a mixture of $Ca(OH)_2$ and alkaline Fly Ash (FA) sorbents. These react with SO_2 and form Calcium-Sulphur compounds. In the wet limestone FGD process complex acid base reactions take place, either under forced or natural oxidation conditions. It is classified as a non regenerable method. (Ibid..) The desulphurization reactions themselves take place in the scrubber: Limestone slurry is fed into the scrubber pumped to the top of the scrubber and then sprayed into it from above in order to react with the SO_2 from the flue gas which is also fed into the scrubber. Hereby a gypsum slurry ($CaSO_4 \cdot 2H_2O$) is produced as a result of the desulphurisation process. (fig. 9.) (Cordoba 2015: 275-277)

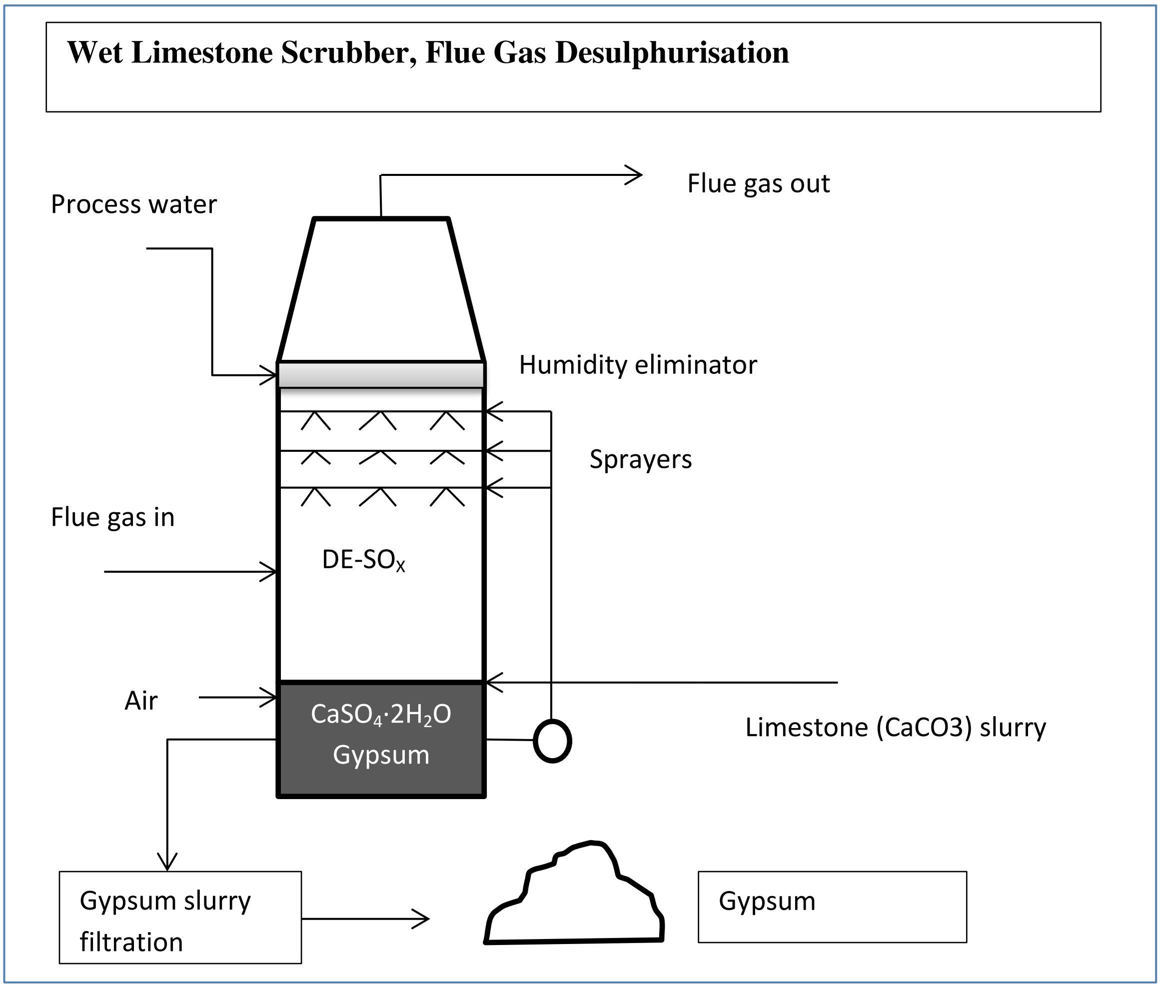

Fig. 9 Wet Limestone Scrubber, Flue Gas Desulphurisation (based on Córdoba 2015: 274–86)

In the after treatment process from the gypsum slurry the final gypsum by-product is produced. This FGD gypsum end product usually contains 10 % of water by weight and has to be transported to landfills or utilized in certain applications such as the cement industry or in wallboard manufacturing. Furthermore, in regions where water is scarce for power plants, filtered water during the FDG process can be recirculated to the scrubber. The wet limestone FGD systems are able to remove SO_2 with an efficiency ranging from 92 % to 98 %. (Cordoba 2015: 277)

Another variation is the magnesium enhanced lime (MEL) process. In this case the lime is enhanced with magnesium, which makes the absorber slurry much more alkaline, because of greater solubility of magnesium salts compared to calcium sorbents. As a result MEL processes can achieve higher SO_2 removal efficiencies in smaller scrubbers than are used for pure limestone processes. Which method to use then depends on the initial circumstance such as the availability or price of magnesium and limestone. (Cordoba 2015: 277)

A very different option for FGD, but which is limited to use it close to maritime environments is the seawater FGD system. These systems make use of the natural alkalinity of seawater in order to neutralise SO_2 by absorption from the flue gas. The end product from this desulphurization technology SO^2_4- is entirely dissolved in the sea water, which is discharged back to the sea, after its Ph level has been restored to natural levels. The advantage of this technique is that there is not waste product to dispose of. However, seawater systems efficiency ranges from 85 % to 98 % for SO_2 removal. (Cordoba 2015: 277)

China has already taken first steps to bring its economy on the path of desulphurisation and hence reduction of SO_2: In the 11th Five-Year Plan, which was launched in 2006, the government set the goal for reducing SO_2 emissions by 10 %. In this case the policy was implemented aggressively. In only two years' time, China had installed desulphurisation equipment in a bigger number of power stations than the USA had implemented in thirty years. Furthermore, China has also applied other measures than FGD such as regulations in vehicle emissions. In 2013, the government introduced new standards, which obliged oil refiners to reduce the sulphur content of diesel from 350 ppm to 10 ppm and that of gasoline from 150 ppm to 10 ppm, which is the exact same standard as is followed by the European Union. Moreover, the improvement of fuel will as a result also enable China's vehicle fleet to adopt more advanced emission control technologies and by this further reduce tailpipe emissions. The changes aim for a large effect for diesel and heavy-duty trucks, which only make up a small share of total vehicles but account for the greater part of emissions. However, before the background of China's economic growth, it should be pointed out that it is not enough for China to implement these regulations solely in the area of traffic to successfully combat pollution, also from SO_2. (Alcorn 2013: 1973-1974)

9.2. Denitrification of flue gas

Nitrogen oxides (NO_X) play a very prominent role in the chemistry of the atmosphere. The major sources of NO_X are combustion processes at high temperatures. NO_X formation from combustion is directly related to the nitrogen content of the fuel. NO_X are precursors of particulate matter and with SO_X contribute to the formation of acid rain. Particularly NO_2 has negative health effects on humans leading to adverse respiratory effects including airway inflammation. People with respiratory conditions such as asthmatics are at higher risk. Furthermore, NO_X reacts with ammonia, moisture, and other compounds to form small particles, which penetrate deeply into sensitive parts of the lungs and can cause or exacerbate respiratory disease, such as emphysema and bronchitis. Moreover, existing heart disease can be aggravated, leading to increased hospitalisations and premature death. (EPA 2016c) Environmental effects of NO_X are very diverse: Besides the formation of acid rain, increased nitrogen content in water bodies, especially in coastal area and disturbances of the chemical balance of nutrients consumed by aquatic organisms is possible. Excess nitrogen leads to eutrophication, which in turn leads to oxygen depletion and reduces fish and shellfish populations. Moreover, N_2O, as a greenhouse gas, contributes to global warming. (XRT 2016) Moreover, ozone production in the troposphere is directly related to the presence of NO_x. The process hereby is known as the ozone engine. (fig. 10)

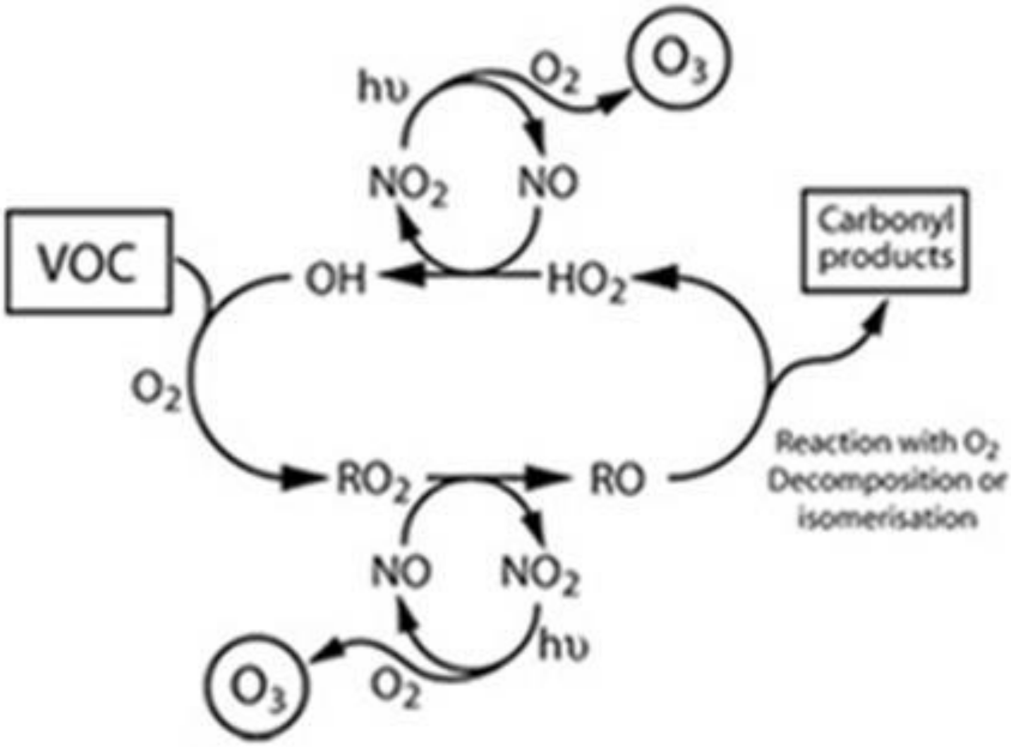

Fig. 10. Ozone Engine (VOC 2001)

Tropospheric ozone in turn has very adverse effects on human health and is a precursor to smog. Health effects include the induction of respiratory symptoms, decrements in lung function and inflammation of airways (EPA 2016). Furthermore, ozone formation through NOx and secondary aerosols may also lead to climate forcing effects. (Zhao et al. 2013: 9869)

Today the most dominant technology for denitrification is the selective catalytic reaction. During this process NO_X are catalytically reduced to N_2 with the help of NH_3 (ammonia). Typically the SCR (Selective Catalytic Reaction) is located between the economizer and the air preheater in the power plant in order to reach the temperatures needed for a successful reaction. The desired products of the reaction are N_2 and H_2O, which are environmentally harmless. (Global CCS Institute 2016)

In order to control NO_X emissions from coal fired power plants and consequently reduce secondary particulate matter, the Chinese government has started to employ SCR technology. In 2012, about a quarter of total generating capacity from coal was equipped with SCR technology. The 12th Five Year Plan from 2011 has even set the ambitions target of the installation of SCRs for almost all CFPPs. However, the total generating capacity of CFPPs with SCR installation, has only increased minimally between 2012 and 2014, namely from 819 GW to 820 GW respectively. (However, still higher than in EU, Japan and United States combined) (Li et al. 2015: 227-228)

An independent study led under the China Project at Harvard University, found that China is indeed making great progress in the combat against SO_2. However, the Chinese policy also showed a major weakness, because it only focused on this one pollutant, while others where not receiving enough attention. Therefore, while it is true that SO_2 levels fell, mono-nitrogen oxides, primarily from heavy industry and cars continued to rise significantly. In the 12th Five-Year Plan (2011-2015) the PRC outlined the first targets to reduce mono-nitrogen oxides. Furthermore denitrification equipment is started to be installed in major stationary emission sources such as power plants and industrial plants like steel mills. (Alcorn 2013: 1973–74) A study from 2013 predicted an increase of NO_X by 36 % in China from 2010 levels compared to 2030, with existing pollution control and legislation. However, the study also calculated other scenarios in which new energy-saving policies, including life style changes, structural adjustments and energy efficiency but also end of pipe control measures are implemented. The result in these scenarios ranged between a potential decrease of 30 % to 70% of nitrogen oxides emissions, depending on the extent of efforts. (Zhao et al 2013: 9893) Clearly, there is still a lot of potential to reduce NO_X in China. While it is true that China has successfully started to implement NO_X abatement measures up to date, the fast motorisation and the increase in vehicles in the future should be taken into account. In front of this background further opportunities to enhance De-NO_X in China should be seized as soon as possible, to prevent further environmental harm.

9.3. Carbon Capture and Sequestration

The greenhouse gas CO_2 plays the most prominent role in global warming and climate change. Therefore every country should set the reduction of CO_2 emissions as a priority goal. Carbon dioxide is being exchanged between the atmosphere, ocean and earth's surfaces continuously. It is being produced or consumed by various microorganisms, plants and animals. CO_2 is a natural part of the carbon cycle. However, certain human activities are disturbing the natural carbon cycle in two ways: they add more CO_2 to the atmosphere and alter the ability of natural sinks, such as forests to remove CO_2 from the atmosphere. There are also natural sources for CO_2. However, the increase in CO_2, which has been going on since the industrial revolution, is to a great part attributable to human related emissions. The main sources for human related CO_2 emissions are the combustion of fossil fuels such as coal, natural gas and oil for energy and transportation, land use change (also deforestation) and certain industrial activities. (EPA 2016a)

With 10,975.50 Million tons of CO2 equivalents China is the largest emitter of CO_2 worldwide. (World Resources Institute 2014) Although China is highly engaged in renewable energy implementation, the rising energy demand suggests that the number of coal fired plants will not significantly decrease in the short term-perspective. In order to combat CO_2 emitted by coal fired power plants in the country the installation of carbon dioxide capture and sequestration technologies (CCS) is vital. With CCS the carbon from fossil fuels electricity generating power plants can be captured in a way that it can be injected afterwards into storage sites in deep underground rock formations or reused in industrial production. CCS has a potential of hindering 90 % of carbon from electricity production to enter the atmosphere. Another reason why CCS is attractive to the Chinese government is that the use of this technology legitimises the continued use of coal in the future. Although the leadership of the country already took first steps in CCS technology development by establishing a national research and development program, there is little progress in the development and deployment of CCS. According to Lai and co-writers a major obstacle in this area are the costs. The relatively high capital and operational costs pose uncertainties for firms, which are interned in developing CCS technology. The implementation of CCS would translate to an additional cost to electricity rate payers of 1.6–2.4 c/kWh for coal-fired plants and 1.5– 3.7 c/kWh for gas-fired plants. (Lai et al. 2012: 635-636)

A study by Dahowski et al. has found that as China has a huge theoretical and geographical dispersed capacity for geologic carbon dioxide (CO_2) storage. It could withhold a 2,300,000 $MtCO_2$ in onshore basins with deep saline-filled sedimentary basins. Around 90 % of all Chinese large stationary CO_2 point sources are less than 160 km away from the next potential deep geologic storage formation. It was found that storage in these large deep saline formations at estimated transport and storage costs of less than 10 $\$/tCO_2$ are relatively cost effective. (Dahowski et al.2009: 2849–56) Recently, Chinese government is showing signs of increased commitment to CCS. Because the technology is still in its infancy in China, the NDRC adopted a new policy, which should promote development and demonstration of CCS projects. The government expects that this policy could support CCS in reaching large scale application and commercialization by giving local governments the task to embrace pilot projects along newly developed guidelines, which can improve research on capturing CO_2, not only for combatting climate change but also for creating economic benefits. However, the policy only has little effects as long as the cost problem is there. The only possibility to lower costs for CCS is by implementing large-scale demonstration projects, where different technologies could be tested on a commercial scale. The policy promotes CCS, but companies do not want to engage in CCS development because the price for it is too high to be able to pass it on to the consumer. (Moch and Forbes 2013) An investigation, which dates back to 2007 also showed that CCS does have significant potential for development in China. But in order to get the large scale development of CO_2 storage demonstration projects started more funding has to come from the government, multinational agencies, but also from abroad. The result would be a widespread deployment of these technologies both in China and the rest of the world. (Meng et al. 2007: 2376). Lai and his colleagues also point out that in the absence of explicit carbon pricing through market or regulatory mechanisms, recouping operational costs of CCS remains a significant barrier. (Lai et al. 2012: 636)

10. Conclusion and Recommendations

The People's Republic of China has undoubtedly a huge task to fulfil. After decades of efforts to elevate the country out of poverty, boost the industry and propel China among the leading economies of the world, the bitter fruits of this success story are now harvested. Energy has become an issue in two ways in China. On one hand its future security has to be ensured, as dependencies on international oil markets increase. On the other, pollution has reached levels, which are seriously impairing the health of the population and are becoming increasingly a burden on the environment and the economy. However, there are ways out of the problem. A more sustainable energy production in the future will have to lie on three main pillars in China: Increasing renewable energy deployment, decentralisation of energy systems and treatment of pollutants. The Chinese government showed commitment to the utilisation and growth of renewable energy. However, although there are supporting laws in place and large scale projects are being implemented; severe inefficiencies and inconsistencies in the regulative and monitoring field are obstacles to successful deployment of renewable energy, especially in the wind sector. The Chinese government has to organise and harmonise the implementation of renewable energy projects in order for them to be efficient. Although renewable energy does not deplete scarce resources and does not emit significant GHG emissions, it should be noted that it is of little use if it is not utilized and power generation is running idle. For the wind and solar sector opportunities have been recognised by the government and initiatives taken. While solar energy is growing steadily, wind power grew over-proportionally and uncontrolledly in comparison to grid capacities. The government should develop grids in a way that all the idle wind power can be integrated into the system. For geothermal and bioenergy a lot of potential has been found for China. However, this potential is not sufficiently utilised and the government should promote respective projects in the field. Especially Miscanthus as a bioenergy crop is an attractive option as it could restore degraded land in China. Hydropower should not be considered for energy production China on a large scale anymore, due to its ecological impact and implications for food production. Furthermore, renewable energies could significantly lessen China's dependence on energy imports and hence ensure energy security even in the case of economic volatility of prices, crisis or wars abroad. The second pillar, decentralised energy will make the Chinese energy system not only more sustainable by the enhanced use of renewables but also more economic due to eradication of losses for long range transmission of energy. This is especially important as load centres and renewable energy resources are far away from each other in China. Furthermore, as renewable energy is volatile, energy fall outs can be easily overcome by power fed in from many small scale sources and ensure energy supply and hence energy security. Moreover, excess energy from small private renewable sources can be fed into the grid and is not lost as inefficiencies. China did start a number of decentralised energy projects. However, here again the recurring lack of efficient regulative measures impairs the development and deployment of the technology. The third pillar, flue gas treatment is necessary, because it can be expected that the coal fired power plants of the PRC will not shut down in the short term perspective, as the demand is rising with population and living standards. Furthermore, severe environmental damage has already been done, which makes immediate action indispensable. For this purpose different flue gas treatment technologies should be installed such as FGD, $DENO_X$ and CCS. China has already been active in this field and has seen a huge increase in the implementation of FGD. However, $DENO_X$ and CCS have to be promoted equally in the future, if pollution and GHG emissions are to be reduced. Finally, concerning all three pillars it should be pointed out that insufficient activity, investment and innovation in R&D are serious obstacles for the development of sustainable energy technologies in China.

The thesis explored the various important transformations and innovations that have to be made in order to ensure a secure and sustainable energy supply in China. By exploring the possibilities and capacities for sustainable energy generation in China, it has been found that such a transformation is possible, as the country has vast renewable resources at its disposal. The first steps have already been taken and the efforts made by the Chinese government, enterprises and people are recognized in this work. The findings of this thesis should make a little contribution to the great project of transforming China into a greener economy. The course China takes will not only affect the country's domestic environment and the future of millions of Chinese, but will have implications for the whole world. What the outcome will be in future decades, time will tell.

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