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# Energy modeling towards low carbon development of Beijing in 2030

**Guangling Zhao [1]*, Sha Chen[2], Josep M. Guerrero[3] and Kejun Jiang[4]**

1 Department of Energy Conversion and Storage, Technical University of Denmark, Risø campus, Frederiksborgvej 399, Denmark
2 Environmental & Energy Engineering College, Beijing University of Technology, Beijing, China
3 Department of Energy Technology, Aalborg University, Denmark, email: joz@et.aau.dk
4 Energy Research Institute, National Development and Reform Commission, Beijing China
* Correspondence: guaz@dtu.dk.; Tel.: +45-93511749

## Abstract

Beijing, as the capacity capital of China, is under the pressure of climate change and pollution. Nonrenewable energy generation and consumption is one of the most important sources of $CO_2$ emissions, which cause climate changes. This paper presents a study on the energy system modeling towards renewable energy and low carbon development for the city of Beijing. The analysis of energy system modeling is organized in two steps to explore the potential renewable energy alternative in Beijing. Firstly, a reference energy system of Beijing is created based on the available data in 2014. The *EnergyPLAN*, an energy system analysis tool, is chosen to develop the reference energy model. Secondly, this reference model is used to investigate the alternative energy system for integrating renewable energies. Three scenarios are developed towards the energy system of Beijing in 2030, which are: (i) *reference scenario 2030*, (ii) *BAU* (*business as usual*) *scenario 2030* and (iii) *RES* (*renewable energies*) *scenario 2030*. The results shows that the share of renewables can increase to 100% of electricity and heat production in the RE scenario. The primary fuel consumption is reduced to 155.9 TWh, which is 72 % of fuel consumption in the reference scenario 2030.

Key words: Renewable energy; energy modeling; low carbon; Beijing.

## 1. Introduction

Low carbon cities, with low greenhouse gas (GHG) emissions, high renewable energy fraction, and efficient energy unitization are expected to play an important role to achieve the goal of low carbon society. The reason that cities are an important player in the transition to a low-carbon society is that they have a high current contribution to GHG emissions. The contributions are projected to continue to grow considering population and economic activity growth, and high energy consumption in cities [1-3]. A few low carbon city indicators are promoted to combine national strategy and local development, such as energy use and waste disposal [4]. The energy sector is the largest source of man-made $CO_2$ emissions. Energy is also used directly or indirectly in economic activities. The cities consume more than 75% of worldwide energy production and generate 80% of carbon emissions [5]. Cities need various energy supplies without interruption to power economic and social activities of human-beings. Angelidou suggested the transition to smart cities should begin now and start by selecting a few domains or high polluted sectors, for example energy sector, transportation sector [6]. The challenges of low carbon energy transition is lie in renewable energy conversion efficiency and cost comparing with fossil fuels [7,8]. Rather than seeing challenges as forces of opposition, they are seen as opportunities for renewable energy to grow, improve, and adjust in a way that leaves themselves more competitive better off [9]. The importance of the low carbon energy transition on small scales is pointed out by analysing two case studies [10]. Cities have the responsibility to cut down theirs carbon emissions and minimize the pollutants to the atmosphere. One of the effective strategies is to modify energy consumption and change behavior. The reduction of energy consumption even by a small amount at the individual level, can translate into large reductions in the amount of energy source that needs to be harvested. The cities and regional governments –both small and large- are in the position to reduce their impacts on reducing energy consumption and improving energy efficiency. The scenarios related to energy demand are modelled, particularly those relating to built environment, transportation, and building and urban utilities [11-13].

In the case of China, the Chinese government signed the Paris Agreement on climate agreement 2016 to cut its carbon emissions per unit of GDP by 60-65% by 2030 from 2005 levels, which was set 40-45% in 2020 in Copenhagen in 2009 [14]. China also aimed to increase the share of non-fossil fuel sources in primary energy consumption to about 20% and peak its carbon emissions by 2030 [15]. The Chinese central government intends to convert the energy system into a sustainable system and a system based on more renewables under the climate change and international and national environmental pressure. This ambitious encourage a growing body of research engaged in exploring the low carbon technologies and GHG emissions reduction in individual cities from different perspectives in China. In the building sector, after reviewing and comparing a few low carbon technologies in an island of China, the authors pointed out ''*the most positive effect of implementing the assessed technologies lies in their GHG emission reduction and employment generation*'' [16]. Li conducted energy performance and carbon emissions simulation of the city Macau. Both Li and Huang pointed out the solar energy production had the largest potential of carbon emissions reduction by building sector with no surprise [13, 16]. The important parameters of city planning are identified to reduce household GHG emissions from empirical studies of five neighborhoods in Beijing [17]. These studies focused on the specific low carbon technologies integration or assessment. One of the most important requirements of low carbon society is to build sustainable energy system in the city long-term planning [18,19]. Scenario analysis is the common method to predict the potential future progress of several possible energy models both inside and outside China [20,21]. These studies pointed out the fossil fuel consumption and efficient use of material and energy during urban development can help to discharge and emission of pollutants to the environment. In China, the studies about renewable energy technology or integration of them into energy systems are on the national level instead of city or regions [22,23]. This is probably due to the fact that, in China, the decision-making structure is a top-down approach especially for the long term planning or strategy [24]. The city' energy strategy and planning has significant influence in determining the energy and carbon profiles of China. The urban activities contribute the largest share of the total commercial energy consumption, which was more than 80% in 2014 [25].

Beijing, as the capital of China, has high energy consumption and low energy resources on the contrary. The majority of fuel consumed in Beijing is coal, which has to be transported from coal rich provinces such as Shanxi, Inner Mongolia, and Hebei. The consumption of coal in energy and industry sectors was to blame for GHG emissions [11,26]. As it become more efficient to transmit electricity compare to transport coal, the government tends to transmit electricity between regions More than half of the electricity consumed in Beijing is transmitted from these three provinces in 2014 [27]. In rural area of Beijing, the major energy consumption is for space heating and cooking [28]. It is obvious that the higher energy consumption of fossil fuels is the main cause of GHG emissions. Few studies are carried on exploring the potential renewable energy scenario of Beijing in the future. The objective of this paper is to model potential energy scenarios with ‘zero coal consumption’, which is also the energy development strategy of Beijing [29] . It means the alternative energy sources need to substitute coal in the energy system.

Therefore, this paper aims to capture a relatively complete picture of energy scenarios by exploring alternative energy resource and potential GHG emissions reduction in Beijing. This paper is organized in four sections described as blew. The first section of this paper introduces the importance of energy use and carbon emissions at the city level. The second section presents the methodology employed to model energy system. Energy scenarios formalization and model development process is elaborated in this section too. The third section presents the results and discussions of the energy scenarios. The conclusion is conducted in the fourth section.

## 2. Methodology

In this section the methodology applied in this study and energy modeling process is presented. The primary goal of the article is to build an energy system model for Beijing, which covers heat, electricity together with a wide range of renewable energy resources alternatives. The energy analysis structure and scenarios are described followed the advanced energy system analysis computer model *EnergyPLAN*. A reference model is created based on the energy tool *EnergyPLAN*. The developed model is then used as the energy system of Beijing to exploring the low carbon scenarios transition of Beijing society. In our study, the simulation of the energy system could identify the quantitative comparison between reference scenario and new heat strategy scenarios in terms of primary energy consumption and carbon emissions.

### 2.1 The *EnergyPLAN* model

The *EnergyPLAN* model is an advanced computer tool for modeling energy system. The *EnergyPLAN* model can help in the development of national or regional energy planning strategy based on technical and economic analysis. This model had been used to model a number of cases of energy system and 100% renewable energy plans for cities and countries [30-32]. It can also been employed to analyses new heat technology integration in the system [33,34]. The *EnergyPLAN* is a deterministic input-output energy system modelling tool, which is able to create annual analyses of different energy systems on an hourly level. The structure of the *EnergyPLAN* model is described in Fig.1. The inputs are energy demands (electricity and heat), renewables’ capacities, capacities of the individual energy producers, energy mix of thermal power plants and the choice of a number of different energy strategies and regulation. The model requires broad range hourly distributions of electricity and heat demand as well as the distributions for energy productions from wind, photovoltaics (PV), river hydro and similar energy sources. In this paper, the electricity hourly distribution data is collected from State Beijing Electric Power Company and the heat hourly distribution is obtained and modified from company and authorities in Beijing. The outputs are energy balances and annual energy productions, fuel consumptions and $CO_2$ emissions and the share of renewables.

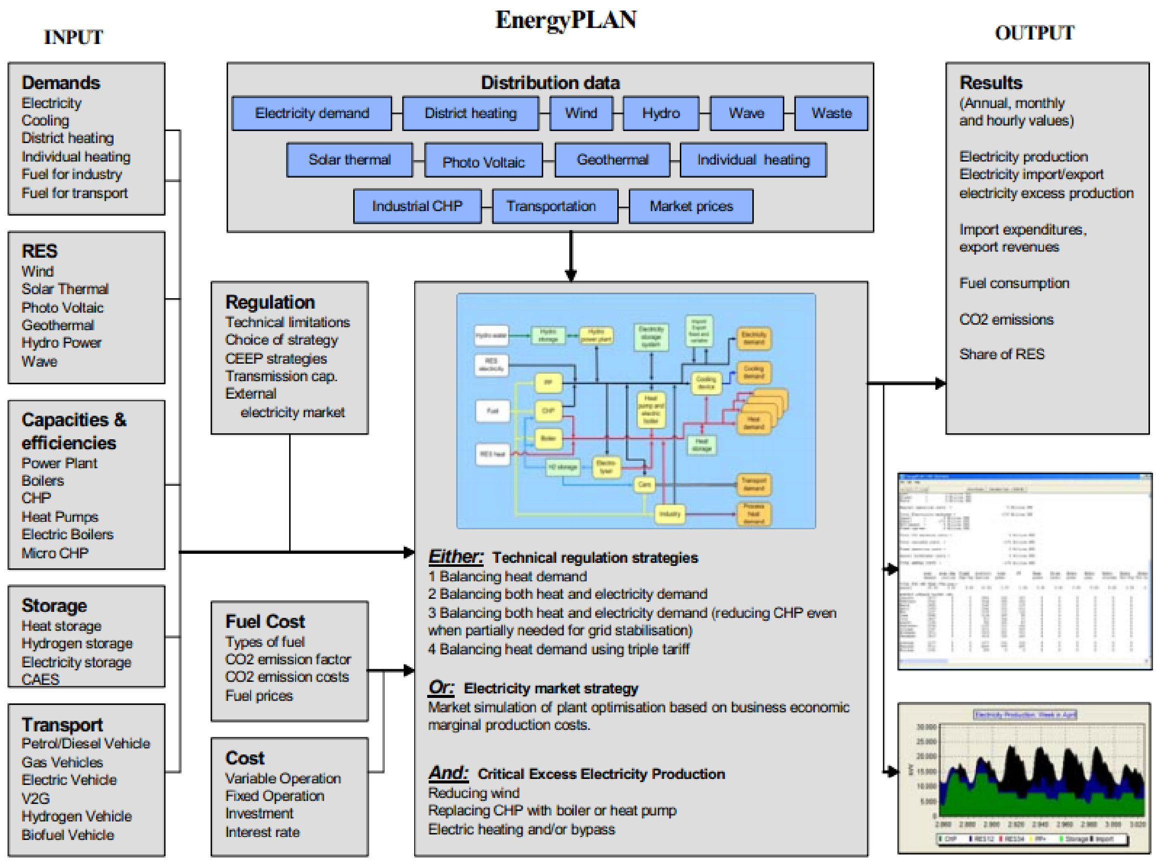


Figure 1. The structure of *EnergyPLAN [35]*

## 2.2 Model process

The future energy demand is determined by population, economic, and many other factors, which let energy demand hardly predicted [36,37]. Most of studies by researchers or organizations predict energy demand by lots assumptions based on scenario analysis [37]. A large amount of electricity can be imported from neighbor power grids to Beijing. The purpose of this paper is to model and compare potential energy situations in which are not implemented yet. The comparison will be carried on by primary fuel consumption, the proportion of renewable sources in the system and the total $CO_2$ emissions from the system. In this paper, the electricity production in 2030 is estimated based on the assumption of annual increased rate 1.5 %, which is also the national energy demand increased rate of China by IEA from 2014 to 2030 [38]. This increased rate is also a quarter of the electricity production increased rate of Beijing from the year of 2005 to 2014, which was the fast economic developing period. The electricity production is estimated to be 46.83 TWh in 2030. The heat demand is predicted based on the annual increase rate of 1.56 %, which is a quarter of annual heat demand increased rate of Beijing from the year 2005 to 2014. The total heat demand is estimated to be 62.9 TWh, which includes district heating in the urban areas and individual heating in the rural areas (table.1).

Typical potential renewable energies in Beijing are solar energy source, which is also the most popular renewable source for heating production in China [39,40]. The potential solar energy resource is predicted 350TWh in Beijing [41]. The capacity of solar photovoltaics (PV) for electricity generation was 25 MW in 2014. There is no clear statistic data about the total capacity of solar thermal for heating production in 2014. Based on current building area and condition, there will be 700 million $m^3$ building's roof which are suitable for solar panel [42]. Together with the development of concentrated solar power, solar energy may dominate the renewable supply potential within urban areas in the future. Another attractive renewable energy source is biomass and municipal solid waste. The potential energy production is 6.7 TWh from agricultural and forestry residues, and 16 TWh of energy can be obtained from municipal solid waste [41]. Wind energy and hydropower can provide high renewable fractions outside the urban area of Beijing, which is different picture compare with national and regional energy consumption in general[43].

The planning for the energy development of Beijing is 'zero coal consumption' in the urban areas. In Beijing, many of coal-fired power plants have been constructed since 2000, meaning that it is technically capable of continuing to operate for decades to come. Even though the Beijing municipality has taken steps to invest in developing and constructing highly efficient natural gas power plants and renewable energy power and to retire some of its most inefficient existing coal-fired capacity, It is likely not economic realistic to come close all the coal power plant considering the higher percentage of the coal plant in the current electricity system. The economical option is to find the alternative energy source replacing all the coal from power plant, heat plant and heat boilers. Technologically, the potential alternative energy sources could be natural gas biomass [44, 45].

In this paper, the timeline is set 2030. The goal is set as 'no coal consumption' in the whole municipality of Beijing by 2030. For the purpose of this work, three scenarios have been created (table.1). The first one, reference scenario, it is developed based on the energy situation in 2014, in which the increased electricity and heat consumption is satisfied with the import fossil fuels with no measurement of controlling GHG emissions. The second one, *BAU* (business as usual) scenario presents a policy as usual in which natural gas replace coal in the electricity and heat consumption to reduce GHG emissions from energy system. The third scenario, *RES* (renewable energies) scenario presents a model of the system with unitization of renewables in the form of biomass energy and PV power to replace fossil fuels completely in the energy system.

Table 1. Electricity and heat demand in the scenarios (TWh)

| Demand | Reference scenario 2030 | *BAU* scenario 2030 | *RES* scenario 2030 |
|---|---|---|---|
| **Electricity Demand** | **46.83** | **46.83** | **46.83** |
| **Heat Demand** | **62.90** | **62.90** | **62.90** |
| CHP | 7.53 | 7.53 | 19.58 |
| District heating boilers | 36.16 | 36.16 | 24.11 |
| Individual heating boiler | 19.21 | 19.21 | 19.21 |

### 2.2.1 Modeling reference scenario

In order to create the future scenarios and analyze the energy system a reference model had to be created first. The year 2014 has been used as a reference year since it is the newest year with available data. The installed capacities of power plants have been taken from the China Electric Yearbook [26]. The total electricity production was 36.9 TWh. The fuels consumed for electricity and heat production is taken from Beijing Statistical yearbook [46], as well as the energy demands of the building, industry sector. The hourly distribution of electricity demand for the year 2014 had been used here. They were obtained from State Beijing Electric Power Company the meteorological data including outside temperature wind speeds and solar insulations were taken from report [41].

As it can be seen, basically all of the produced electricity in the city comes from thermal power plants with only 150 MW of installed wind power, which produced only 0.32 TWh of electricity in 2014. A small amount of hydropower plants was installed in the Beijing energy system, which produced 7 TWh of electricity in 2014. Even though solar energy is the most competitive renewable energy source in Beijing, there is only 0.02 TWh of electricity produced from solar PV. The heat production includes district heating system (CHP and boilers) and the individual heating boilers. The supply of district heating started from the 15th of November in 2014 to the 15th of March in 2015. The total district heating supply was 53.6 TWh in these four months, which included 15.4 % of heating generated from CHP plants and 84.6 % of heating generated from district boilers. The individual boilers were mainly installed on the countryside, which were used for heating and cooking. The efficiencies of coal and natural gas stove are 40 % and 50 % respectively, which are much lower compare to the modern stoves [47]. Table 2 presents the energy system modeling from the actual energy consumption data of Beijing and the *EnergyPLAN* simulation. It shows that the *EnergyPLAN* simulation is closed to the actual energy data in 2014. The difference is below 1 %, which proves that the distribution data and efficiency data used in the model is satisfactory enough to simulate the future energy system of Beijing. The *EnergyPLAN* model is capable of simulating energy system of Beijing accurately. The assumption, which is used to develop the reference scenario 2030, is based on the energy resource distribution in 2014.

Table 2. Validation of the 2014 reference model.

| Technology | Fuel input TWh | | Difference TWh | difference % |
|---|---|---|---|---|
| | Actual data 2014 | EnergyPLAN simulation | | |
| **Electricity production** | | | | |
| Coal | 29.29 | 29.24 | 0.05 | 0.17 |
| Oil | 0.75 | 0.75 | 0.00 | 0.00 |
| Natural gas | 37.76 | 37.39 | 0.37 | 0.98 |
| Hydropower | 7 | 7 | 0.00 | 0.00 |
| Wind power | 0.32 | 0.32 | 0.00 | 0.00 |
| Solar | 0.02 | 0.02 | 0.00 | 0.00 |
| **Heat production** | | | | |
| Heat production of CHP unit | 12.59 | 12.58 | 0.01 | 0.08 |
| Heat production of Boiler | 44.13 | 44.10 | 0.03 | 0.07 |
| Individual heat demand | 34.31 | 34.31 | 0.00 | 0.00 |

### 2.2.2 *BAU* scenario (business as usual scenario)

The current energy strategy of Beijing is to replace coal by natural gas and increase the renewable energy propositions in the energy system at the same time. Coal consumption will be replaced by natural gas, which can increase fuel utilization efficiency. Based on this principal of the energy strategy, the *BAU* scenario is developed. The detail inputs and technologies are present in table 3. The potential capacity of wind power and river hydropower could reach 1 GW and 1.5 GW respectively. The heat demand includes district heating system and individual heating system. In the district heating system, 15.6 % of heating demand is met by CHP natural gas plants, 84.4 % of heating demand is supplied by natural gas boilers, which is the same heat distribution in the reference scenario 2030. This scenario is created mostly using known technologies which can be adapted in current infrastructures. This scenario assumes that the current market can develop and improve existing technologies.

Table 3. Details of energy conversion units and input in the *BAU* scenario

| Energy conversion technology | Efficiency | Input | |
|---|---|---|---|
| | % | GW | TWh |
| **Electricity Demand** | | | **46.83** |
| Power Plants unit (natural gas) | 38.00 | 1.00 | |
| CHP unit (natural gas) | 38.00 | 4.50 | |
| River hydropower | | 1.50 | |
| Wind | | 1.00 | |
| Solar Photo Voltaic | | 6.00 | |
| CSP Solar Power | | 1.00 | |
| **Heat Demand** | | | **62.89** |

| | | |
|---|---|---|
| CHP unit (natural gas) | 52.00 | 7.53 |
| District heating boiler | | 36.16 |
| Electric heating | | 6.00 |
| Solar thermal | | 2.00 |
| Natural gas stove | 50.00 | 13.20 |

### 2.2.3 *RES* scenario (renewable energy scenario)

An overview of reference scenario and *BAU* scenario shows that Beijing's energy system will be still dominated by fossil fuels either coal or natural gas. A 100% renewable energy scenario is promoted here to reduce the energy dependence on fossil fuels, in which all fossil fuels are replaced by renewables in the Beijing energy system by 2030. The list of the installed energy technology can be found in the table 4. Biomass and waste are as the main energy sources replacing fossil fuels. The scenario treats heat technologies as a significant technology as the heat production is relatively higher than the electricity production in Beijing as shows in table 1. Combine heat and power (CHP) is global recognized a significant technical choice to improve energy system efficiency [48, 49]. In the *RES* scenario, it is assumed that one third of district heating boilers are updated by CHP plants.

In the district heating system, the more efficient CHP plants expands their capacity and produces 24.07 TWh more than that in the BAU scenario, which primarily come from replacing the low efficient district heating boiler plants. The heat production from the district heating boilers decreases to 12.06TWh. The reason for having relatively larger amount of district heating boilers is that the heating system with increasing unbalance in the electricity supply generated by renewables and CHP plants, demand the flexibility of the system by installing electric heating and heat boilers. The individual heating system is mainly located in the rural area of Beijing. There are no district heat system infrastructures, so it might take decade to install the district heating system. Electrical heating and solar thermal are promoted to replace fossil fuels consumption and increase energy efficiency.

Table 4. Details of energy conversion units and input in the *RES* scenario

| Energy conversion technology | Efficiency | Input | |
|---|---|---|---|
| | % | GW | TWh |
| **Electricity Demand** | | | **46.83** |
| Power Plants unit (waste) | 38.00 | | 16.00 |
| CHP unit (biomass) | 38.00 | 4.50 | |
| River hydropower | | 1.50 | |
| Wind | | 1.00 | |
| Solar Photo Voltaic | | 6.00 | |
| CSP Solar Power | | 2.00 | |
| **Heat Demand** | | | **62.89** |
| CHP unit (biomass) | 52.00 | | 31.60 |
| District heating boiler (biomass) | | | 12.06 |
| Electric heating | | | 13.20 |
| Solar thermal | | | 6.00 |

## 3. Results and Discussion

After running the simulation for scenarios with the help of *EnergyPLAN*, the results are analyzed. The results of three scenarios are presents based on the fuel consumptions, the share of renewable resources for electricity and heat production and $CO_2$ emissions (table 5). As expected the reference scenario has the highest fuel consumptions and $CO_2$ emissions because of the low efficient heat system and low proportions of renewables. In the *BAU* scenario, the share of renewables is 11.66 % of total fuel consumptions, thanks to the increased renewables in the electricity production. The primary energy consumption is decreased 32.94 TWh compared to the reference scenario which is 216.58 TWh. The $CO_2$ emission is decreased to 34.19 Mt, which is because of the replacement of coal by natural gas in terms of electricity and heat production. The RES scenario is the one with 100% renewables and zero $CO_2$ emissions in the year 2030. Compared to the reference energy system, the *RES* scenario is able to reduce the primary energy consumption to 155.90 TWh. One of the critical issues about renewables especially solar and wind in the energy system is critical excess electricity production (CEEP). Surplus electricity production is defined as situations in which the electricity production exceeds the demand in a given time and area. The electricity production from solar power plant cannot change with electricity demand hour by hour [50]. The electricity production from CHP plants depends on the heat demand. In the city of Beijing, the heating system for building is only supply for four months of the whole year. In order to increase the shares of renewables and CHP plants in the energy system and avoid 'surplus electricity production' at the same time, the electrical heating and district boilers are designed in the energy system. In these three scenarios, analyses of energy system based on hour-by-hour have been used to increase electricity from renewables and CHP to an amount ensuring that the unused electricity consumption is low. These analyses also ensure that the heat supply and electricity supply is balanced. In the *RES* scenario, the expansion of solar energy and CHP plants leads to an excess electricity production 0.76 TWh.

Table 5. Results of the scenarios analysis

| | Reference scenario 2030 | *BAU* scenario 2030 | *RES* scenario 2030 |
|---|---|---|---|
| Fuel consumption (TWh) | 216.58 | 183.64 | 155.90 |
| RES shares % | 3.39 | 11.66 | 100.00 |
| $CO_2$ emissions (Mt) | 67.62 | 34.29 | 0.00 |
| CEEP (TWh) | 0.01 | 0.23 | 0.76 |

Table 4 presents the primary energy consumption by sources to produce the electricity and heat demand. Fig. 2 further illustrates the share of renewables in the scenarios shown in Table 4. There are, however, large differences between the scenarios with regard to energy sources and conversion technologies. The reference scenario keeps the same energy source distribution to the energy system of the year in 2014. The major two energy sources are coal and natural gas. In the *BAU* scenario, the main energy sources are natural gas with little contribution of oil and renewables, which account for approximately 15% and 11% respectively. The energy system of the *RES* scenario is built up by difference renewables mix. The mainly newly installed renewables are solar energy and biomass.

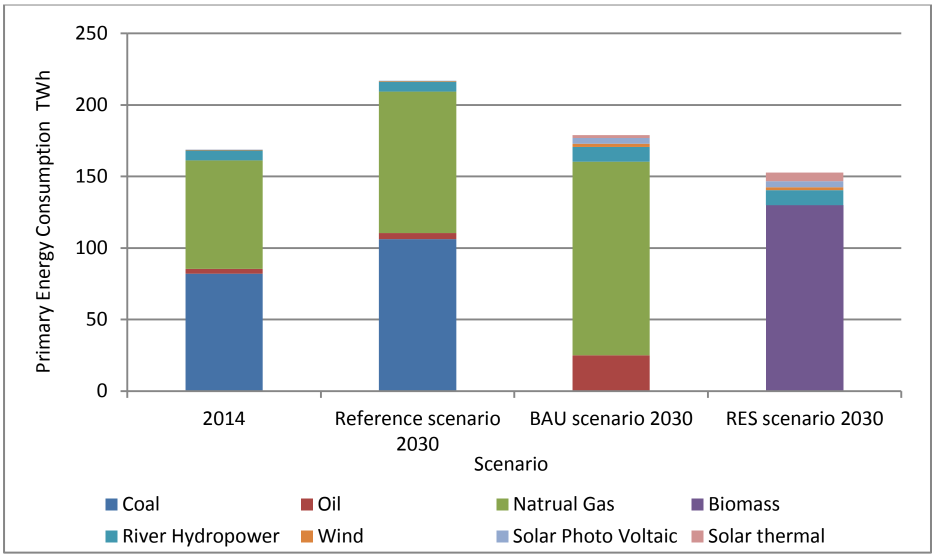


Figure 2. The Primary Energy consumption by different sources Unit: TWh

There is great potential for the solar energy source in Beijing and the government should encourage both industrial and individual costumers to further invest solar energy. In the paper, two approaches are employed to solar accessibility solar energy, which are solar photovoltaics for electricity production and solar thermal energy for heat production [50]. As shown in the analysis in this paper, if solar PV installed on all building roofs, the energy production could be 6 TWh. Together with solar thermal energy, the total solar energy can supply estimated 10.18TWh, which accounts for 9.3 % of total energy demand in the year of 2030.

In the *RES* scenario, a 100% renewable energy system is possible with consumption of 113.93 TWh biomass and 16 TWh waste both in terms of electricity and heat production. The energy utilization of agricultural and forestry residues can increase the harvested rate of biomass, which potential reduces the environmental impact to the soil [51, 52]. Beijing is a modern city with low agricultural land and activity. This determines that there are not enough biomass sources available in Beijing. The biomass sources need to be transported from neighbor provinces, which will cause high impacts from transportation [53]. The overusing biomass for energy system could cause the impact to the land use and ecosystem [54]. The potential conflicts of biomass energy utilization are due to different demands and expectations of land resource, as biomass energy requires the conversion of agricultural land from food crop production to the biomass production. The energy utilisations of waste products from activities of agriculture and forest, and human-being were highlighted, as they can avoid both direct and indirect land-use change [55]. From conversion technology perspective, the second-generation biofuel technologies were promoted to void the arable land cultivation for biofuels [56]. The high proportion of natural gas and biomass in the energy system might cause the price of electricity and heat increasing. The potential economic consequences need to be addressed in the future study.

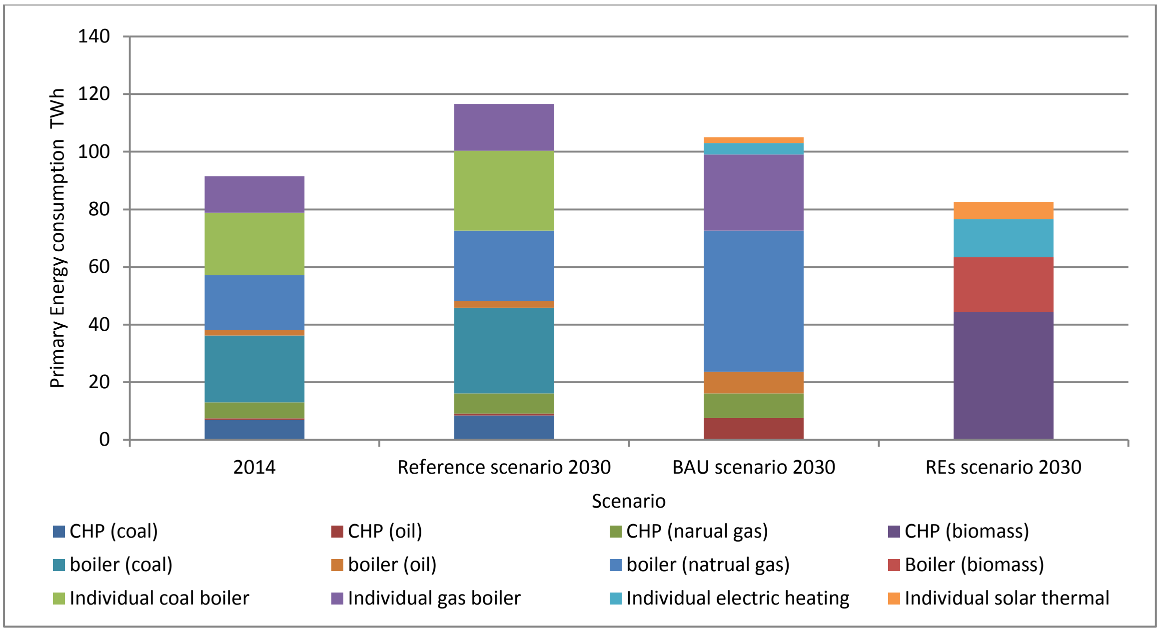


Figure 3. The Primary Energy consumption of heat production by different sources Unit: TWh

Fig.3 presents the primary fuel consumption for heating supply both district heating and individual heating. In the year 2014 and reference scenario, fossil fuels still play the major role in the both district heating system and individual heating supply. The low efficiency of coal boiler and stove cause the high primary fuel inputs in the two scenarios. Compared to the reference scenario, it is clear that the energy efficiency has been increased with introducing high efficiency CHP in district system and electric heating and solar thermal in the individual heating system in the *BAU* and *RES* scenarios. The primary energy input is decreased to 105 TWh/yr of *BAU* scenario by employing high efficiency gas boilers. In the *RES* scenario, the primary energy input is decreased to 82.63 TWh/yr by introducing electric heating to the individual heating system and increasing the share of CHP plants in the district heating system. In the individual heating system, the traditional conventional boiler is replaced by the demand for electricity which is produced by biomass CHP plants and biomass condensing power plants. The annual primary fuel input is decreased to 19.2 TWh which is 32.4 TWh in the *BAU* scenario and 43.97 TWh in the reference scenario.

The heat productions account more than half of the primary fuel consumptions in three scenarios in 2030 and also in 2014 in Beijing. So it is important to increase energy efficiency and renewable energy proportion in to eliminate fossil fuels in heating sector. The current heat situation of heating system is diverse due to the local cultural and weather and unbalance infrastructure development between urban area and countryside. High efficiency technologies like CHP plants, heat pumps and solar thermal and traditional low efficiency technologies like coal stoves constitute the current heating system in China [57, 58]. As there is no district heating infrastructure in the rural area, the heat alternative technology promoted here is electric heating and solar thermal energy for the individual heating system. The result shows the annual primary fuel input of *RES* scenario decease 13.2 TWh compare to the *BAU* scenario with natural gas stove and small amount of electric heating and solar thermal energy. The critical issues on the solar thermal is to decrease the cost and to attract more individual costumers to install.

## 4. Conclusion

This paper presented the 100% renewable energy scenario of Beijing in 2030. This study begins by developing a model capable of simulating the energy system of Beijing relating to electricity and heat. The accuracy of the reference model was validated by comparing the results of the model with actual statistics of the year 2014. The validation proved that the model is accurate to model future energy analysis of Beijing. Based on the detailed hourly distribution, three scenarios were developed and analyzed, which are reference scenario, *BAU* scenario and *RES* scenario. With the help of this *EnergyPLAN* model, these three scenarios were analysis and compared regarding renewable energy integration and $CO_2$ emissions.

The results show the *BAU* scenario and *RES* scenario can help with decrease the annual primary fuel consumption compared to the reference scenario 2030. The reduction of primary fuel consumption is by 15% in *BAU* scenario and 28% in *RES* scenario. The calculated $CO_2$ emissions produced by reference scenario are two times higher than the *BAU* scenario with natural gas replacing coal in the electricity and heat production. The energy system of the *RES* scenario presented based on solar energy and biomass, optimization of heat system is 100% renewable energy system with zero $CO_2$ emissions. Results reveal that the most significant low carbon technologies are in the heating sector compare the *RES* scenario with *BAU* scenario. The crucial of energy development is balance electricity and heat productions by renewables. The analysis highlights the important of heating system both district heating and individual heating system. Firstly, in the urban district heating system, the high efficient technologies like CHP should be promoted in the future. Secondly, in the rural heating system the suitable infrastructure for district heating need to be constructed to improve heat consumption efficiency, which is also calls for a long time horizon. Electric heating and solar thermal are good alternative heating supply if the electricity are generated from renewables.

It should see that it is very ambitious to have 100% renewable energy system in Beijing. It cannot be reached without an effective policy support. The transition to 100% renewable energy is a long term objective. The investment of energy project is a complex and process and need to start from the energy infrastructures both for electricity transmission and heat supply. Further research needs to cover the transport model especially electric vehicles.

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## Reference

[1] Keirstead J, Jennings M, Sivakumar A. A review of urban energy system models: Approaches, challenges and opportunities. Renewable and Sustainable Energy Reviews. 2012;16(6):3847-3866.

[2] Glaeser EL, Kahn ME. The greenness of cities: Carbon dioxide emissions and urban development. Journal of Urban Economics. 2010;67(3):404-418.

[3] Dhakal S. Urban energy use and carbon emissions from cities in china and policy implications. Energy Policy. 2009;37(11):4208-4219.

[4] Lin J, Jacoby J, Cui S, Liu Y, Lin T. A model for developing a target integrated low carbon city indicator system: The case of Xiamen, China. Ecological Indicators. 2014;40:51-57.

[5] Lazaroiu GC, Roscia M. Definition methodology for the smart cities model. Energy. 2012;47(1):326-332.

[6] Angelidou M. Smart city policies: A spatial approach. Cities. 2014;41:3-11.

[7] Kahrl F, Williams J, Jianhua D, Junfeng H. Challenges to China's transition to a low carbon electricity system. Energy Policy. 2011;39(7):4032-4041.

[8] Su M, Chen B, Xing T, Chen C, Yang Z. Development of low-carbon city in china: Where will it go? Procedia Environmental Sciences. 2012;13:1143-1148.

[9] Chu, S. and Mjumdar, A. Opportunities and challenges for a sustainable energy future. Nature. 2012; 488(7411): 294-3. .

[10] Mattes J, Huber A, Koehrsen J. Energy transitions in small-scale regions–What we can learn from a regional innovation systems perspective. Energy Policy. 2015;78:255-264.

[11] Liu Z, Liang S, Geng Y, et al. Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites: The case of Beijing, Tianjin, Shanghai and Chongqing. Energy. 2012;37(1):245-254.

[12] Eicker U, Monien D, Duminil É, Nouvel R. Energy performance assessment in urban planning competitions. Appled Energy. 2015;155:323-333.

[13] Li Z, Quan SJ, Yang PP. Energy performance simulation for planning a low carbon neighborhood urban district: A case study in the city of Macau. Habitat International. 2016;53:206-214.

[14] Wang Ye. China signs Paris agreement on climate change. http://news.xinhuanet.com/english/2016-04/23/c_135305180.htm. Updated 2016. [ Accessed 06/05, 2016] .

[15] IEA. World energy outlook 2015. Paris, France. 2015.

[16] Huang B, Mauerhofer V. Low carbon technology assessment and planning—Case analysis of building sector in Chongming, Shanghai. Renewable Energy. 2016;86:324-331.

[17] Qin B, Han SS. Planning parameters and household carbon emission: Evidence from high-and low-carbon neighborhoods in Beijing. Habitat International. 2013;37:52-60.

[18] Yang L, Li Y. Low-carbon city in China. Sustainable Cities and Society. 2013;9:62-66.

[19] Liu Z, Guan D, Crawford-Brown D, Zhang Q, He K, Liu J. Energy policy: A low-carbon road map for china. Nature. 2013;500(7461):143-145

[20] Mohareb EA, Kennedy CA. Scenarios of technology adoption towards low-carbon cities. Energy Policy. 2014;66:685-693.

[21] Phdungsilp A. Integrated energy and carbon modeling with a decision support system: Policy scenarios for low-carbon city development in Bangkok. Energy Policy. 2010;38(9):4808-4817.

[22] Wang H, Zhou P, Zhou D. Scenario-based energy efficiency and productivity in China: A non-radial directional distance function analysis. Energy Economics. 2013;40:795-803.

[23] CHAI, Q. and ZHANG, X. Technologies and policies for the transition to a sustainable energy system in China. *Energy.* 2010; **35**(10): 3995-4002.

.

[24] Lee, c.w. and Zhong, J. Top down strategy for renewable energy investment: conceptual framework and implementation. *Renewable Energy.* 2014; 68: 761-773.

[25] NBS, ed. China statistical yearbook 2015. Beijing, China: National Bureau of Statistics of China. Beijing, China. 2015.

[26] Feng, Y., Chen, S. and Zhang, L. System dynamics modeling for urban energy consumption and CO 2 emissions: a case study of Beijing, China. *Ecological Modelling,* 2013; 252: 44-52

[26] Editorial Board of China Electric Power Yearbook, ed. China electric power yearbook 2015. China Electric Power Press. Beijing, China. 2015.

[28] Liu W, Spaargaren G, Heerink N, Mol AP, Wang C. Energy consumption practices of rural households in north China: Basic characteristics and potential for low carbon development. Energy Policy. 2013;55:128-138.

[29] Zheng J. 01/12, 2016-last update, Capital to wipe out coal use by 2020 [Homepage of CHINADAILY], [Online]. Available: http://www.chinadaily.com.cn/china/2016-01/12/content_23038558.htm [04/22, 2016].

[30] Lund H, Mathiesen BV. Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. Energy. 2009;34(5):524-531.

[31] Lund H, Münster E. Management of surplus electricity-production from a fluctuating renewable-energy source. Applied Energy. 2003;76(1):65-74.

[32] Lund H. Large-scale integration of wind power into different energy systems. Energy. 2005;30(13):2402-2412.

[33] Østergaard PA, Mathiesen BV, Möller B, Lund H. A renewable energy scenario for Aalborg municipality based on low-temperature geothermal heat, wind power and biomass. Energy. 2010;35(12):4892-4901.

[34] Xiong W., Wang Y., Mathiesen B.V., Lund H. ,Zhang, X. 2015. Heat roadmap China: new heat strategy to reduce energy consumption towards 2030. *Energy,* **81**, pp. 274-285.

[35] Lund H. Choice awareness and renewable energy systems. Aalborg, Denmark: Aalborg Universitet. 2009.

[36] BP. BP energy outlook to 2035. Country and Regional Insights–Global. 2016. https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2016.pdf. Updated 2016. [ Accessed 16/05, 2016]

[37] Suganthi L, Samuel AA. Energy models for demand forecasting—A review. Renewable and sustainable energy reviews. 2012;16(2):1223-1240.

[38] IEA. World energy outlook special report 2015: Energy and climate change. Paris, France. 2015.

[39] Fang X, Li D. Solar photovoltaic and thermal technology and applications in China. Renewable and Sustainable Energy Reviews. 2013;23:330-340.

[40] Shi J, Su W, Zhu M, et al. Solar water heating system integrated design in high-rise apartment in China. Energy Build. 2013;58:19-26.

[41] Sha C, Pianpian X, Kejun J. Research on climate change adaptation of the energy sector in Beijing. Beijig, China. 2016.

[42] Yan D. The renewable energy will reach 8% of Beijing by the end of 13th five year planning. Available from: http://www.ccchina.gov.cn/Detail.aspx?newsId=55945&TId=57%22%20title=%22%E5%8C%97%E4%BA%AC%E5%8A%9B%E4%BA%89%E2%80%9C%E5%8D%81%E4%B8%89%E4%BA%94%E2%80%9D%E6%9C%AB%E6%96%B0%E8%83%BD%E6%BA%90%E5%88%A9%E7%94%A8%E6%80%BB%E9%87%8F%E5%8D%A0%E6%AF%94%E8%BE%BE8%. Updated 2015. [Accessed 06/01, 2016].

[43] Zhao G, Guerrero JM, Pei Y. 2016. Marginal Generation Technology in the Chinese Power Market towards 2030 Based on Consequential Life Cycle Assessment. Energies, 9(10), 788: 1-14.

[44] Baliban RC, Elia JA, Floudas CA. Simultaneous process synthesis, heat, power, and water integration of thermochemical hybrid biomass, coal, and natural gas facilities. Computers& Chemical Engineering. 2012;37:297-327.

[45] Baxter L. Biomass-coal co-combustion: Opportunity for affordable renewable energy. Fuel. 2005;84(10):1295-1302.

[46] BSB, ed. Beijing statistical yearbook. Beijing Statistical Bureau; Chinese Statistical Publishing House. Beijing, China: 2015.

[47] ADB (Asian Development Bank). Preparing national strategy for rural biomass renewable energy development.. Asian Development Bank Advisory Technical Assistance. 2008 April. Available from: https://www.adb.org/sites/default/files/project-document/68329/40108-prc-dpta.pdf. Updated 2008. [Accessed 06/08, 2010].

[48] Münster M, Morthorst PE, Larsen HV, et al. The role of district heating in the future Danish energy system. Energy. 2012;48(1):47-55.

[49] Smith AD, Mago PJ, Fumo N. Benefits of thermal energy storage option combined with CHP system for different commercial building types. Sustainable Energy Technologies and Assessments. 2013;1:3-12.

[50] Devabhaktuni V, Alam M, Depuru, Soma Shekara Sreenadh Reddy, Green RC, Nims D, Near C. Solar energy: Trends and enabling technologies. Renewable and Sustainable Energy Reviews. 2013;19:555-564.

[51] Pan G, Lin Z, Li L, Zhang A, Zheng J, Zhang X. Perspective on biomass carbon industrialization of organic waste from agriculture and rural areas in china. Journal of Agricultural Science and Technology. 2011;13(1):75-82. Chinese

[52] Zhang Z, Engling G, Lin C, et al. Chemical speciation, transport and contribution of biomass burning smoke to ambient aerosol in Guangzhou, a mega city of China. Atmospheric Environment. 2010;44(26):3187-3195.

[53] Uherek E, Halenka T, Borken-Kleefeld J, et al. Transport impacts on atmosphere and climate: Land transport. Atmos Environ. 2010;44(37):4772-4816.

[54] Abbasi T, Abbasi S. Biomass energy and the environmental impacts associated with its production and utilization. Renewable and Sustainable Energy Reviews. 2010;14(3):919-937.

[55] Searchinger T, Heimlich R, Houghton RA, et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science. 2008;319(5867):1238-1240.

[56] Rowe RL, Street NR, Taylor G. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. Renewable and Sustainable Energy Reviews. 2009;13(1):271-290.

[57] Zhuang Z, Li Y, Chen B, Guo J. Chinese kang as a domestic heating system in rural northern China—A review. Energy Build. 2009;41(1):111-119.

[58] Yan D, Zhe T, Yong W, Neng Z. Achievements and suggestions of heat metering and energy efficiency retrofit for existing residential buildings in northern heating regions of China. Energy Policy. 2011;39(9):4675-4682.