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The Effects of Clean Energy Development on China's Carbon Dioxide Emissions Control

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Abstract—**Climate change is becoming an acute global issue that should be taken seriously by all human beings instead of ignoring it. China, as the world's largest CO2 emitter, its move is vital for the world to deal with the climate change issue. In order to tackle this issue, China announced its Intended Nationally Determined Contributions (INDCs) stating the objective of peaking its CO2 emissions by 2030 while making its best efforts to achieve an earlier peak. To achieve this, various carbon reduction actions need to be implemented and their priority and effects are worth studying. This paper employed a bottom-up modeling approach to examine how different technologies in both the end-use sector and energy supply sector will affect China's future carbon dioxide emissions' trends and in what priority we should deploy them. Results indicated the development of clean energy supply technologies are of great importance to achieve China's carbon reduction goal and should be prioritized. Some other technologies that could potentially contribute to carbon mitigation were also discussed and their impacts were analyzed.**

Keywords-Climate change, Carbon dioxide reduction, Carbon peaking, Clean energy supply

I. INTRODUCTION

Climate change is becoming a more and more urgent and severe issue worldwide owing to its threats to social and economic development of all human beings. Global climate change such as heat waves, rising sea levels and more severe storms, has already occurred across the world, which threatens the quality of human being's life. It will also threaten the biodiversity, ecosystem, causing economic downturn and wars. Thus, climate change is an acute global issue which should be taken seriously by all human beings instead of ignoring it.

Along with its economic development, China has become the world's largest CO2 emitter in 2007 [2], and accounted for more than 25% of the world's total carbon dioxide emissions in 2015 [3]. It is expected that China's carbon dioxide emissions will further increase in the future considering its continuously industrialization and urbanization process and China's move is vital for the world to deal with the climate change issue [4]. In order to tackle this issue, China announced its Intended Nationally Determined Contributions (INDCs) stating the objective of peaking its CO2 emissions by 2030 while making its best efforts to achieve an earlier peak [5]. To achieve this, various carbon reduction actions need to be implemented and their priority and effects are worth studying.

Some international institutes focus on the world's future energy trends and its related carbon dioxide emissions, such as International Energy Agency (IEA) and U.S. Energy Information Administration (EIA). In their energy outlook reports [6,7], they highlighted China's future energy demand and supply status and its impacts on the world energy market. However, they do not pay enough attentions to how China will achieve its INDCs goal and contributions of different technologies in fulfilling the goal. Some studies stated that energy-saving technologies applied in end-use sectors could substantially cut energy demand and thus reduce carbon dioxide emissions [8, 9]. However, they did not evaluate possible changes of energy supply structure relating to this issue. Zhou et al. developed a bottom-up model, named the LBNL(Lawrence Berkeley National Laboratory) China End-Use Energy Model to analyze its future energy balance by constructing two scenarios [10]. However, due to the limit of scenario construction, it only gave how likely China would plan its future energy blueprint rather than making comparisons among technologies that could potentially cut China's carbon emissions in a large amount. Thus, it is of great importance to study how different technologies in both the end-use sector and energy supply sector will affect China's future carbon dioxide emissions' trends and in what priority we should deploy them.

The rest of the paper was organized as follows. Section 2 explained the methodology adopted in this study including its modeling process and scenario settings. Section 3 discussed modeling results in its constructed scenarios and revealed some essential findings. Section 4 concluded key findings in this study and proposed some suggestions.

II. METHODOLOGY

A. A bottom-up Approach

This paper employs a bottom-up approach which separates the overall energy system into three parts: energy-using sector, energy conversion sector and energy-supplying sector. The energy-using sector is considered as an independent variable, thus the energy-supplying sector is regarded as its dependent variable as the energy conversion efficiency is set as parameters. Data for China's energy supply and demand balance in 2014 are applied as the input of the model.

The energy-using sector contains industry, transportation, buildings and others. And energy-using types consist of electricity, coal, oil, gasoline and heat. By adding together these four sectors' distinct energy, the total final consumption of each energy demand is clear, which can be converted into the energy supply sector through the energy conversion sector. The energy-supplying sector contains coal, oil, gas, hydro, wind, nuclear and solar PV. Taking coal as an example, there are mainly three parts of coal demands. The first is directly adding up industry, buildings, transportation and other sectors' coal demands. The second is used to generate heat and the last is for electricity. Therefore, adding up these three parts of coal demand equals to total coal supply.

The priority of electrical generation is given to clean energy such as nuclear, wind, hydro and etc. Installed capacity of these technologies are set. More specifically, distinct installed capacity growth rates and its maximum capacity is taken into account in each scenario. The deficit of electricity supply is generated by thermal power. Total CO2 emissions is the sum of the product of each primary energy's consumption and its CO2 emission coefficient.

The compound annual average growth rate (CAAGR) of different types of energy in the energy-using sector refers to World Energy Outlook. Future energy demand growth through to 2020, 2030 and 2040 can then be estimated.

B. *Scenario Construction*

This paper uses four scenarios: business as usual scenario (BAU), clean supply scenario (CS) , electrification plus clean supply scenario (ELE) and electrification plus gas substitution with clean supply scenario (EG). The purpose is to reveal the role of these key technologies in delivering a low-carbon future.

- Business as usual scenario (BAU)

The BAU scenario is under the condition that technology will develop constantly without any policy or strategy attempting to solve environmental problems. The compound annual average growth (CAAGR) of coal is -1.3%; oil is 1.5%; gas is 4.5%; and electricity is 2.4%. For installed capacity of clean energy, nuclear will increase 4 GW annually, wind will aggrandize 15 GW every year, solar will rise at an annual rate of 15 GW, and hydro will add 5 GW each year, reaching 400 GW by 2030.

- Clean Supply scenario (CS)

The CS scenario assumes a much more aggressive strategy about renewable and nuclear energy development. To be specific, nuclear will increases 10 GW annual; hydro will add 5 GW each year, and we raise the ceiling of hydro's peak to 450 GW by 2040; wind will aggrandize 20 GW every year; solar raises at a rate of 20 GW per year.

- Electrification plus clean supply scenario (ELE)

The ELE scenario is established based on the CS scenario, which assumes that the ELE scenario bears the same clean energy supply as the CS scenario, while it expects that gasoline cars will be partly replaced by electrical vehicles. More specifically, the ELE scenario assumes that 10% of oil will be replaced by electricity by 2030, and 15% by 2040.

- Electrification plus Gas substitution with clean supply scenario (EG)

The EG scenario's renewable energy capacity grows the same as that of the ELE and CS and it also replaces gasoline by electricity in the transportation sector, while replaces the industry sector's gas demand by electricity. More specifically, an addition of 5% of coal in industry is replaced by gas per decade while the supply side stays the same.

III. Results and Discussions

A. *BAU Scenario*

Figure 1 shows: In this scenario, China will not enact any policy controlling greenhouse gas emissions. By 2040, China's energy demand grows form 2000 Mtoe (Million tones of oil equivalent) to 2600 Mtoe. In 2040, within the energy demand sector, industry occupies the largest proportion, which accounts for 44%, dropping down by 6 percentage points compared to the number in 2014. The second one is building, which accounts for 24%. The third one is transportation, whose share is 19%, 5 percentage points above the level in 2014. And the rest is considered as a whole accounting for 13%. This reveals that China's energy demand will increase at a relatively stable rate and not reach a peak at least by 2040 due to the drive of urbanization and industrialization.

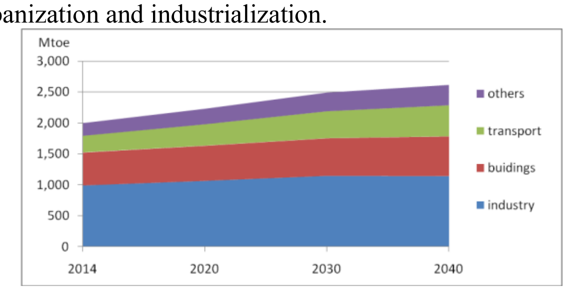


Figure 1. Energy demand in BAU scenario

Figure2 shows that to meet this huge energy demand, the amount of energy supply also grows in a rapid way. The dominant energy is still coal which grows from 1800 Mtoe to 2000 Mtoe, however, the share of it drops substantially from 72% to 59%. Then is oil, which grows stably. Gas doubles the share within just two decades. And renewable energy possess only little share of the whole supply.

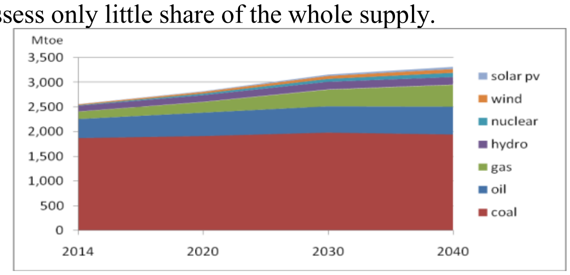


Figure 2. Energy supply in BAU scenario

Figure 3 shows that under these circumstances, the amounts of CO_2 emissions will grow dramatically from 9.0 Gt in 2014 to 10.5 Gt in 2030, and rise slightly to 10.7 Gt in 2040. The emissions promptly increase from 2014 to 2030, then slow down by 2030 yet still rise and far from reaching its peak. Thus, CO_2 emissions in this scenario will constantly rise without a peak which is against the statement that China will reach its CO_2 emissions peak by 2030. Although the share of fossil fuel will drop down apparently and that of clean energy will rise, the amount of CO_2 emissions still grows due to the unalterable amount of fossil fuels. The increase of primary energy particularly coal contributes to the sharp rise of CO_2 emissions.

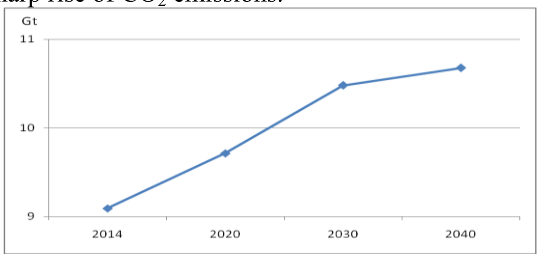


Figure 3. Carbon dioxide emissions in BAU scenario

B. CS Scenario

Figure 4 shows that in this scenario, China develops its renewable energy with a great passion. Energy demand keeps the same pace with the former scenario, whereas, the remarkable distinction appears in the energy supply part. Although coal is still the dominant energy, it will plateau and decrease dramatically from 72% to 52% of the whole energy supply. Oil initially rises and then goes down, however, its share increases from 15% to 18% due to its more rapidly growth rate than the overall growth. In contrast, the amount of gas and other renewable energy expands.

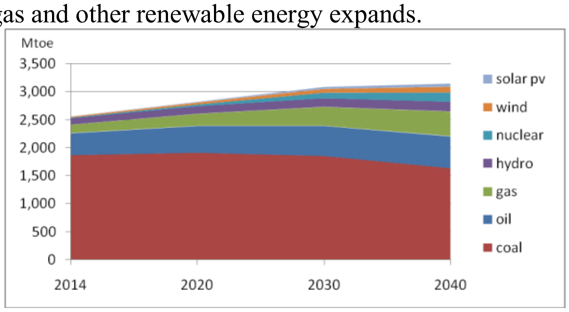
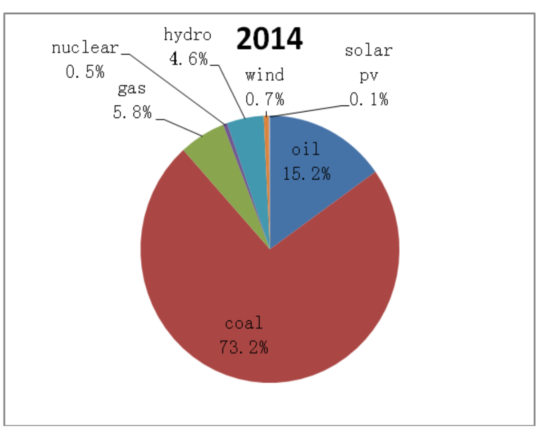


Figure 4. Energy supply in CS scenario



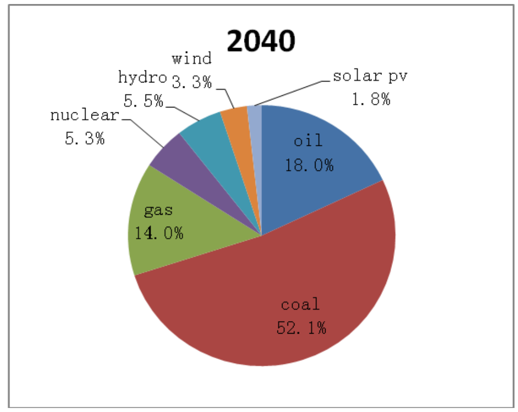


Figure 5. Electricity composition by 2014 and 2040 in CS scenario

Figure 5 shows that moreover, the share of electricity generating will vary dramatically. In 2014, the majority of electricity generating energy was coal. In 2040, with fast-developing clean energy, coal only occupies 38% of the whole supply. On the other hand, the clean ones occupy 55% of the total.

Figure 6 shows that the most significant change is CO_2 emissions. Since clean energy releases no CO_2, and coal will decrease, China will peak its CO_2 emissions nearly 10 Gt by 2030, and then decline tremendously to 9.5 Gt by 2050. In 2040, China's CO_2 emissions will be even lower than 2020's level, reaching 9.7 Gt. Thus, it will achieve the goal China promised, and this is the largest difference between the BAU scenario and this one.

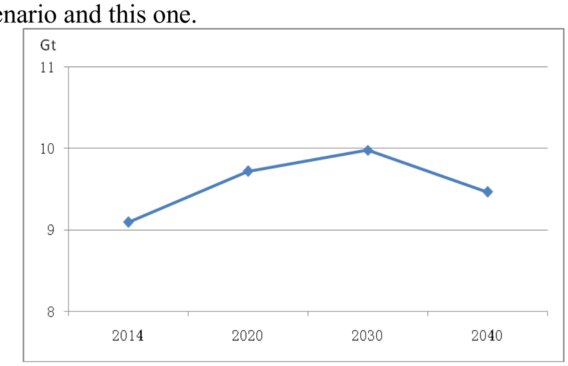


Figure 6. Carbon dioxide emissions in CS scenario

C. ELE Scenario

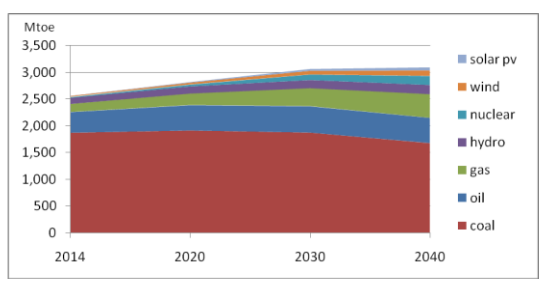


Figure 7. Energy supply in ELE scenario

Figure 7 shows that in this scenario, China not only develops its renewable energy significantly, but also replaces gasoline vehicles with electrical vehicles. However, by 2040, coal is still the leading primary energy form accounting for around 55% of the whole supply. Oil is 15% and gas is 14%.

Figure 8 shows that total CO_2 emissions change slightly compared with the CS scenario since additional electricity is mainly generated from coal. Though coal constitutes highest CO_2 intensity, owing to the high efficiency of electrical cars, less amount of coal is required compared to its equivalent oil consumption, which leads to the consequence of CO_2 emissions reduction. In conclusion, developing electric automobiles can facilitate the reduction of CO_2 emissions.

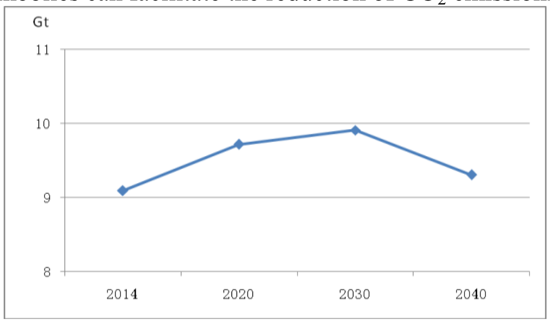


Figure 8. Carbon dioxide emissions in ELE scenario

D. Comparisons Among the Four Scenarios

Figure9 shows that in these four scenarios, one vital difference is their CO_2 emissions trends. In the BAU scenario, it will grow in a rapid way instead of decreasing within two decades. However, by developing clean energy, the decrease of CO_2 emissions is prominent. And the subsequent scenarios change slightly. Hence, in order to realize China's promise that CO_2 emissions will reach its peak before 2030 and undergo reductions, the government has to develop renewable energy dramatically.

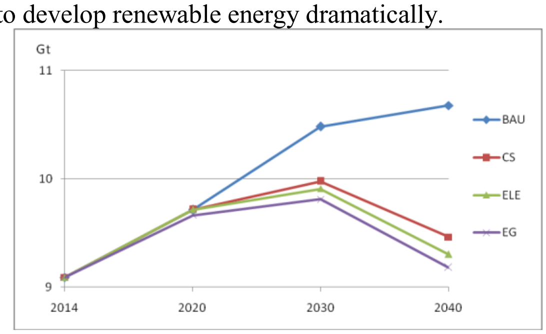


Figure 9. Carbon dioxide emissions in four scenarios

Figure 10 shows that in terms of the energy supply part by 2040, its total sum undergoes a great decline particularly between BAU scenario and CS scenario. This is because a large amount of renewable energy generating electricity replaces coal generation whose transformation process involves loss of heat. Between CS scenario and ELE scenario, the former one's coal consumption is less than that of the latter one due to the fact that extra electricity required by oil substitution is generated by coal. The energy supply in ELE and EG scenarios differs a little since the amount of gas replacement is not a big number compared to the overall amount and their utilization efficiency for heating is close.

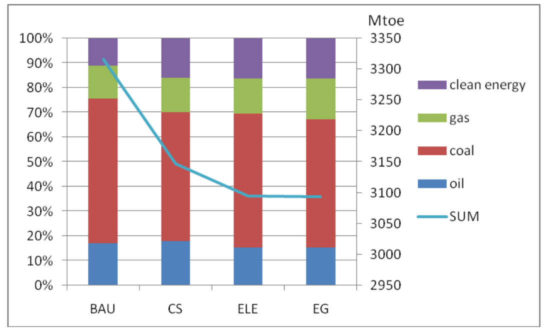


Figure 10. Primary energy supply in four scenarios by 2040

IV. CONCLUSIONS

From the four scenarios, we can see possible trends of future energy demand and supply, and how they balanced each. Industry will remain the main energy consumption sector while the increase of transport is quite notable. Coal will still be dominant in primary energy supply while other forms of energy will expand at a much faster pace. Despite of the large proportion of fossil fuels in energy supply, its share will drastically decrease while the share of clean energy will increase to around 10~15% of total supply. Due to this tendency, it is apparently that each scenario's strategy of reducing carbon dioxide emissions works out to some extent. The most remarkable decline in CO_2 emissions is between BAU scenario and CS scenario. This implies that deploying clean energy supply is the most effective way to control CO_2 both in the short and long terms. Hence, in order to achieve China's plan of peaking its CO_2 emissions by 2030, prioritizing and strengthening the development of renewable energy and nuclear energy is requisite with some other strategies as auxiliaries.

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