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Modeling the Rapid Development of Electric Vehicles and Energy Storage Technology Under China Carbon Neutral Scenario Based on China-TIMES Model

Shu Zhang [1], Wenying Chen [1*]

1 Institute of Energy, Environment and Economy, Tsinghua University, Beijing 100084, China

ABSTRACT

With the target of carbon neutrality in 2060, China's energy system must undergo a huge transformation. Based on the bottom-up energy system model China-TIMES, this paper generates energy consumption, CO2 emissions and technology options for the future deep decarbonization scenario. The model result shows that the peak time of CO2 will significantly affect the emission level in 2050 and will have a crucial impact on the achievement of carbon neutrality. Quantitative analysis indicates electric vehicles and renewable energy will be essential if we hope to accomplish carbon neutrality target. With the rapid development of electric vehicles, the demand for energy storage technology is growing, and the operating mode of energy storage technology will change from charging at night to charging during the day. The coordinated development of electric vehicles, renewable energy and energy storage technology will become a highlight of China's low carbon transition.

Keywords: Electric vehicles, Renewable energy, Energy storage technology, Carbon neutrality, Energy system modeling, TIMES model

NONMENCLATURE

Abbreviations	
EVs	Electric vehicles
RE	Renewable energy
EST	Energy storage technology
LDV	Light duty vehicle
CO2	Carbon dioxide
INDC	Intended Nationally Determined Contribution
PV	Photovoltaic

1. INTRODUCTION

The Paris agreement requires countries set INDCs to control the global temperature rise within 2 degrees in 2100 [1]. In 2020, countries need to update their INDCs to bridge the emission gap. On September 22, 2020, President Xi announced that China would peak CO2 emissions by 2030 and strive to achieve carbon neutrality in 2060. Energy system as the main source of emissions, fine modeling and analyzing its transformation is quite necessary. Due to fast-growing demand and lack of alternative fuels for aviation and navigation, deep decarbonization in the transportation sector has received great attention.

Road transport is the main source of current emissions and one of the most promising area for fuel substitution in transportation [2]. The development of EVs can effectively reduce fossil fuels use, thereby reducing emissions. However, the emergence of many EVs will have a profound impact on the grid load. In the future, the electricity supply will also undergo a huge fluctuation because of high RE penetration [3]. To improve the reliability and stability of grid operation, EST plays an important role in peak load shaving to balance the gap between demand and supply [4].

Existing research focuses on the simulation of the 2 degrees or 1.5 degrees scenario, and there is a lack of research on the realization of carbon neutrality in China. To explore the development of EVs and EST under new climate targets, a dynamic linear programming model China-TIMES which minimizes the discounted cost under socioeconomic hypothesis and technical constraints is applied. The model characterizes more than 600 technologies for energy extraction, conversion, transport and end-use including advanced technologies such as carbon capture and storage, hydrogen, and biofuels.

This paper mainly discusses the coordination between the development of EVs, RE and EST under the tightening carbon constraints and gives the development path and technology choice of EV and EST under China's 2060 carbon neutral scenario.

2. METHODOLOGY

2.1 China-TIMES model

China-TIMES (The Integrated MARKAL and EFOM System) is a bottom-up energy system optimization model developed by Tsinghua University [5]. As a technology-rich model, China-TIMES can accurately depict energy-related CO2 emissions, while facilitating energy policies and climate targets through flexible constraint settings. China-TIMES model covers building, industry, transportation and electricity sectors, and can obtain the technology development path with the lowest system cost under given constraints. In China-TIMES, the energy service demand is exogenously predicted by socioeconomic drivers such as gross domestic product, population, urbanization rate, industrial structure, etc. In addition, China-TIMES model uses price elasticity of demand to respond to the increase in energy costs and indirectly achieve demand side management.

2.2 Electric vehicles and Energy storage technology modeling

For road transport, we have modeled two sizes of public buses, four sizes of trucks, motorcycles, LDVs and other vehicles in urban, rural, and inter-city areas. There are nearly 100 kinds of road vehicles modeling using different fuels for model optimization. In the model, we assume that EVs charge at night and discharge during the day, that is, one-way orderly charging mode.

Under the low carbon development scenario, many fossil fuel power plants will be gradually replaced by PV plants and wind turbines that RE will play a more important role in power supply. Hence, Hydro, solar, oceanic, wind and geothermal energy have all been finely modelled at the latest updated cost.

Since RE is hard to control, power system needs more dispatchable plants to meet complex and changeable demand. The flexible power plants represented by the natural gas turbines can suppress the peak and valley of power load to a certain extent. EST is also a means to regulate peak load [6]. In our model, a variety of high-capacity ESTs including compressed air energy storage, pumped storage hydropower, flow cell battery, Lead-acid battery, flywheels, superconducting magnetic energy storage are considered.

2.3 Scenario settings

To highlight the changes brought about by new climate target, three low carbon development scenarios are established. The two peaking scenarios correspond to China's original INDC commitment [7]. The cumulative emissions from 2010-2050 for PEAK30 and PEAK25 scenarios are restricted within 380Gt and 350Gt, respectively [5]. The last scenario corresponds to China's recently announced long-term CO2 control target. And we set China's per capita carbon emissions to be the same as the world average in 2050 [8]. Because there are few researches on emission path to achieve carbon neutrality, we assume that the cumulative emissions of the ZERO60 scenario do not exceed the carbon budget for achieving the 2 degrees target [9].

Scenarios	Description
PEAK30	INDC scenario 1: emissions peak in 2030, cumulative emissions in 2010-2050 380Gt
PEAK25	INDC scenario 2: emissions peak by 2030, cumulative emissions in 2010-2050 350Gt
ZERO60	Carbon neutral in 2060, carbon emissions per capita in 2050 equal to the global average, cumulative emissions in 2010–2050 290 Gt assumed

3. RESULT AND DISCUSSION

3.1 CO2 emissions under low carbon development scenarios

According to model result, CO2 emissions will be around 10 billion tons in 2020. In the next 10 years, CO2 emissions will peak and begin to decline. However, the peak time and the time to achieve net-zero emissions will affect the emission path and technology choice.

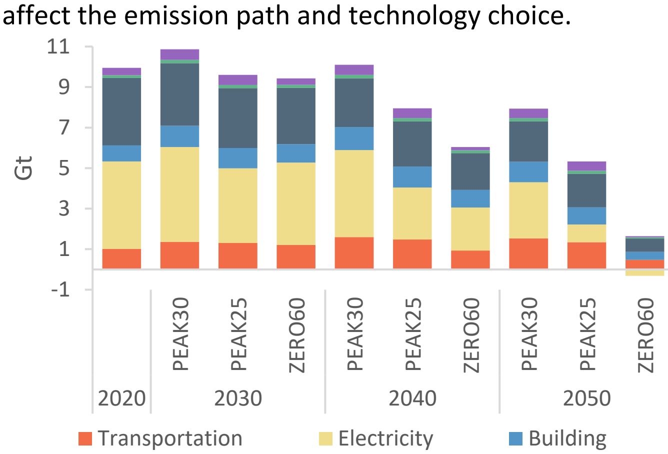

Fig 1 CO2 emissions by Sector

Fig 1 plots CO_2 emissions under different scenarios. Except for the PEAK30 scenario, the emissions in 2030 are lower than in 2020, which shows that to minimize the cost of achieving carbon neutrality, the peak time of CO_2 should be achieved in advance. As for 2050, there will be significant differences in total CO_2 emissions in different scenarios. The PEAK30 scenario will maintain a high emission level (near 8 billion tons CO_2). If CO_2 can peak in 2025, CO_2 in 2050 will be 33% less than the peak in 2030. If net-zero emissions target is to be achieved in 2060, CO_2 emissions from industry sector will decline steadily from now, while transportation sector faces a sharp drop after 2040. Besides, electricity sector will start negative emissions by 2050. Under the stricter CO_2 constraints, emissions from the transportation sector will become increasingly non-negligible. So, emission reduction in the transportation sector will become the focus of the deep decarbonization process.

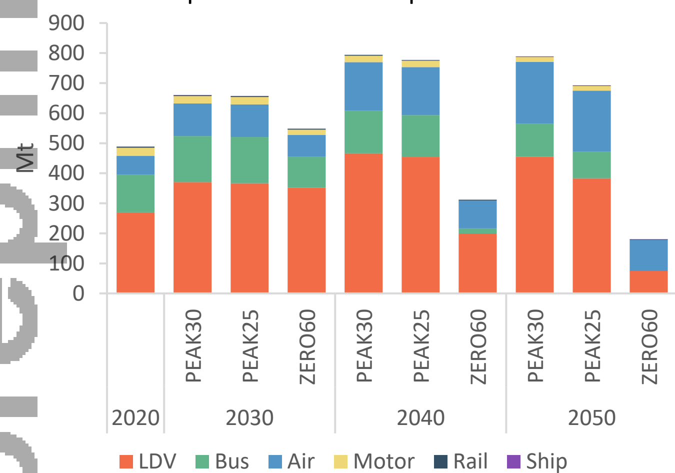

Fig 2 CO_2 emissions in passenger transportation

The transportation sector can be divided into freight and passenger transportation. Freight transportation is more difficult to electrify, thus hydrogen and biofuels will be more realistic choices. Fig 2 shows its CO_2 emissions and proportions of different types of vehicles. Among all vehicles, LDV, bus and motor almost produce the most emissions, and they are also most likely to take the lead in achieving high level electrification. Under the ZERO60 scenario, CO_2 of LDV and bus in 2050 will drop by more than 85% from the peak level in 2030. In contrast, in the PEAK30 and PEAK25 scenarios, LDV and the overall passenger transportation emissions will exceed the current level and bus emissions remain at high level. The high mitigation cost makes it possible to achieve electrification in the transportation sector only under very strong carbon constraints.

3.2 Electric vehicles development

Fig 3 depicts the penetration rate and energy consumption of EVs under different scenarios. For all scenarios, the scale of EVs will maintain a slow growth before 2030. Due to the decline in costs, the blowout development of EVs may arrive around 2035. Under the tightening of carbon constraints, this day will come early. In 2050, under the ZERO60 scenario, the scale of EVs will be more than 30 times the current scale, and 85% of vehicles on the market are electrically driven. Even in the PEAK30 scenario, EVs will still have a 10-fold increase.

The large-scale development of EVs will lead to a rapid increase in electricity demand. In 2050, under the ZERO60 scenario, the electricity demand for EVs will increase nearly 40 times compared with the current situation, and will be close to 1,400 PJ, accounting for 21% of the final energy consumption of the transportation sector.

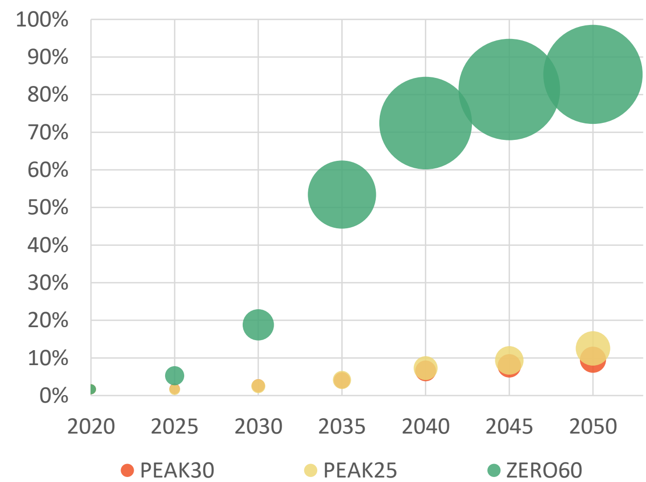

Fig 3 Electric vehicles penetration and energy consumption

3.3 Energy storage technology building and operation

The increasing demand for EVs charging at night, coupled with the inability to generate electricity from PV plants, which will be the important electrical supply in the future, will create a huge demand for day and night peak shifting. It can be seen from Fig 4 that in all scenarios, EST will have a very rapid development. In 2035, the market size of EST will be 2.6, 2.9 and 14 times the current size under PEAK30, PEAK25 and ZERO60 scenarios. In 2050, the market size of EST can reach up to 32 times its current size. However, if vehicle-to-grid technology can be applied, EVs can supply power to the grid and participate in the operation of the power system as a peak load shaving resource, then the demand for EST may decline.

At present, due to the low level of electricity load at night, the EST in the power system presents the characteristics of charging at night and discharging during the day. However, due to the rapid decline in PV costs and the promotion of EVs, after 2030, China's electricity load characteristics will change drastically. The night load will increase, and the daytime net load will experience a trough due to the development of distributed PV. Daytime charging and nighttime discharging operation will flatten the load curve and become the main operating mode of EST.

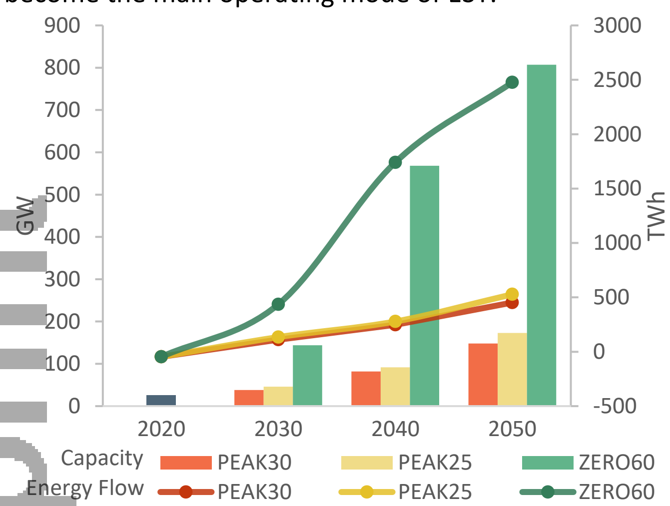

Fig 4 EST installed capacity (GW) and Energy flow (TWh)

4. CONCLUSION

Based on China-TIMES model, time to peak will greatly affect China's CO_2 emission reduction path. Reaching the peak ahead of schedule will greatly reduce carbon emissions in the middle of this century. Regardless of the scenario, emission reduction in the electricity sector is the general trend. And under China's 2060 carbon neutral scenario, all sectors require greater mitigation measures than now. The transportation sector is the most difficult to change and requires early planning and layout.

At present, the transformation of the transportation sector is still in its infancy. After 2030, the transportation sector will show huge mitigation potential due to the rapid development of EVs. By 2050, the market share of electric-driven vehicles will be close to 85% if carbon neutrality is to be achieved.

The rapid development of EVs will increase the electricity demand. If EVs are charged at night, and PVs generate a large amount of energy during the day that the grid cannot absorb, the demand for EST will become unprecedentedly huge. The demand for EST may increase up to 32 times in 2050 than now. In the meanwhile, starting from 2025, the most cost-effective operating strategy of EST will be charging during the day and discharging at night, which is the opposite of the current optimal operating mode.

The development of EVs and EST is a microcosm of China's energy system transformation. The path to deep decarbonization will be needing stringent mitigation measures in all sectors. In this process, not only the energy supply is affected, but consumption habits and energy use behavior may also change. The quantitative analysis results of China-TIMES model can provide reference for policy makers to make plans and decisions to conform to the future development.

ACKNOWLEDGEMENT

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