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Assessing China 2030 carbon emissions from fossil fuels: based on system dynamics model①

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Abstract

The Chinese government has set ambitious targets to reduce the intensity of carbon emissions per unit of GDP by 40% ~45% during 2005 to 2020 and achieve the peaking of CO_2 emissions around 2030. The T21 national development model for China was developed for the purpose of analyzing the effects of long-term national policies that relate to carbon emissions, loss of farm land, water shortage, energy security, food security, and their contributions to this reduction target. The focus of this paper is on the policies that have substantial impacts on carbon emissions from fossil fuels. Four scenarios are developed with the model to simulate future carbon emissions: 1) the BAU (business as usual) scenario, showing the likely results of continuing current policies; 2) the TECH (technology) scenario showing the effects of more investment in renewable energy sources and promoting more energy efficient technologies; 3) the BEHAVIOR scenario, showing how government tax and price policies, together with public education programs, would instigate behaviour changes towards more sustainable living; and 4) the TECH&BEHA scenario, which shows the results of combining scenarios 2 and 3. The simulation results show that CO_2 emissions reduction targets of China are achievable, but also require great effort to put in.

Key words: system dynamics model, carbon emissions, GDP carbon intensity system simulation

0 Introduction

The Chinese government had set two ambitious targets about carbon emissions. The first is to reduce the intensity of carbon emissions per unit of its GDP by 40% ~45% by 2020, compared to 2005 and intends to increase the share of non-fossil fuels in primary energy consumption to around 15% by 2020. The other is to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. The targets to reduce emissions intensity are on par with those implicit in the US and EU targets[1]. How will China achieve these targets? Some researchers have done scenario analyses to calculate sectoral emissions and their mitigation potentials, and they have showed that China's carbon emissions in major sectors will likely increase in the future[2,3]. In view of this, what are the implications for the country's general development goals of trying to achieve these targets? The T21 China model can demonstrate the results of various possible policy combinations used specifically to achieve these targets and show how these efforts relate to China's overall social and economic development prospects.

CO_2 reduction is a complicated systematic project that necessitates integrated policies and measures. Furthermore, it is also a long-term behavior without short-term effects. Thus, the future impacts of investments and measures should be evaluated comprehensively in order to identify emerging issues associated with the process of sustainable development while making policies.

1 Model consrtuction

The T21 national development and planning model has been applied to over 20 countries [4-7], and T21 China was jointly developed by the Institute of Scientific and Technical Information of China and the Millennium Institute. It is extended and modified according

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to China's situation and research needs based on the framework of T21. It was developed to analyze the effects of long-term national policies, primarily related to carbon emissions, loss of farm land, water shortage, energy security, and food security[8-10].

The general overviews of the causal relationships of CO_2 emission from fossil fuels and cement industries on which the scenarios are based are represented by the arrows, shown in Fig. 1. Fossil fuel consumption in China comes primarily from three sources: production in industry and agriculture, transportation, and electricity generation. Production is affected by many factors, including oil price and life expectancy shown in the figure. Other factors are not shown here. Transportation is determined by both wealth (related to GDP) and population size, shown here, and other factors. Similarly electricity generation is also driven by GDP and population size. Real GDP and population (in 0 – 100 + one-year age cohorts) are endogenously modelled in T21. Fossil fuel consumption determines CO_2 emissions, which in turn affects health and life expectancy. Life expectancy further affects production and total population, thus forming the feedback loops. This figure is in reduced form to illustrate how causal relations have impacts across sectors.

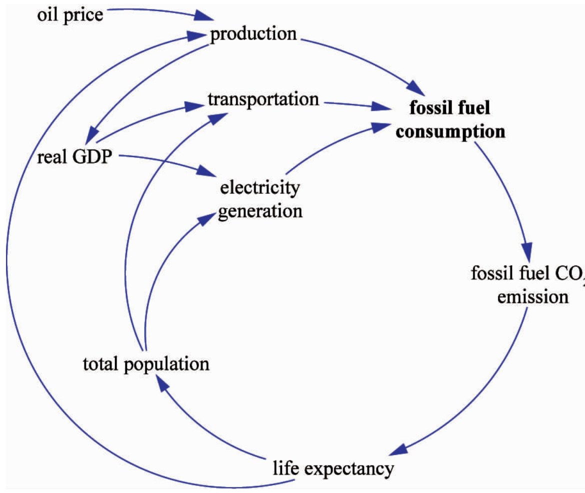

Fig. 1 General causal relations of fossil fuel CO_2 emission

The actual causal relations in the T21 model are much more detailed and specifically developed for China. In Fig. 2, an example of such relationships is presented for cement demand. Starting from the right side of the figure, cement demand is first split into domestic demand and net export demand. Domestic demand during 1990 ~ 2013 has consumed about 99% of cement production. Domestic demand is determined by the activity of five uses: urban residential construction

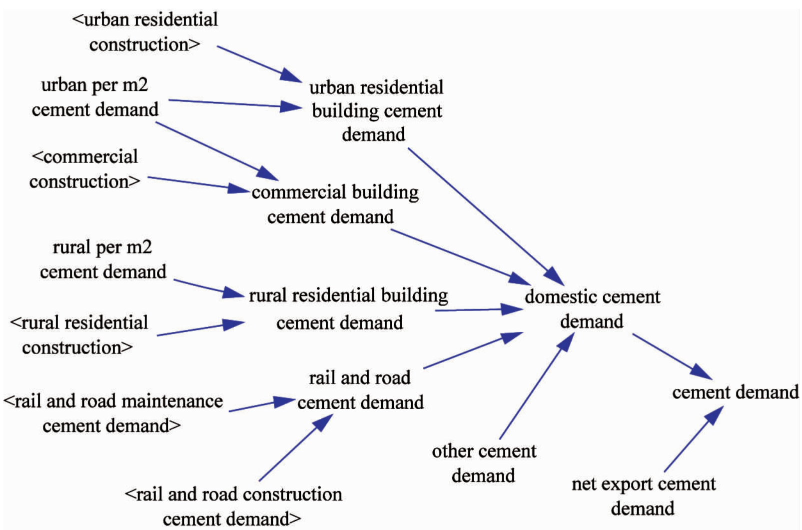

Fig. 2 The actual cement demand sector in T21 China

demand, commercial construction demand, rural residential construction demand, rail and roads demand, and other demand. Each demand is further determined by the variables to its left. Urban residential construction demand is determined by two variables: urban residential construction measured in square meters, and cement needed per square meter of construction. During 1990 ~ 2013, cement demand from urban residential construction accounted for 30% ~ 40% of domestic demand. Future urban residential construction cement demand depends primarily on how much larger urban per capita residential space will grow from about 30 square meters at present and how large urban population will be. The variables enclosed by < > are computed from other sectors of the model, and cement demand computed in this sector is used by other sectors to determine how the demand is produced (by either rotary or vertical kilns), and then how much energy (primarily coal and electricity) will be consumed and how much CO_2 will be emitted. This figure illustrates one of the many subsectors that make up the model and shows the causal relations that are represented by quantitative equations in the model in order to generate the scenarios over time.

The change of any single variable leads to a new simulation analysis of the model. Based on this analysis, we can look forward to possible major challenges encountered in the process of CO_2 reduction and any potential impacts. Furthermore, the model could be re-simulated by changing several or series of variables. This could provide insights into the possible impacts of different strategies.

2 Historical trends related to carbon emissions

Since its economic reform and open door policy started from 36 years ago, China has experienced explosive economic growth. Between 1990 and 2013, total population increased about 19%, from 1.14 billion to 1.36 billion, while real GDP increased 831% (9.74% pa). According to China Statistical Yearbook 2014, per capita GDP in 2013 reached 43,320 RMB, almost 7,000 US dollars.

With this fast growth in income and wealth, living standard and consumption patterns have seen dramatic change, which has direct impact on carbon emissions. A brief description of some of the main sources of CO_2 emissions is presented below.

In 2013, vehicle sales in China were almost 22 million, and China was the world's largest vehicle market. The total private car ownership in China grew by more than 100 times from 8.2 million in 1990 to 883.9 million in 2012. To manufacture a vehicle requires on average about 2 tons of iron and steel. In addition, vehicles also require parking spaces, driving infrastructure, and fuel to operate. The inputs into auto manufacturing, infrastructure construction and vehicle operation all contribute significantly to CO_2 emissions.

Housing standards, measured by per capita residential living area, have increased at a fast pace, from 13.7 square meters in 1990 to about 32.9 square meters in 2012 in urban areas. Due to tight land control policy and lack of timber resources, the primary type of housing in China is high rise apartments to satisfy the residential needs of its people. These use a lot of cement and steel. Each square meter of these high rise buildings needs 300 – 400kg of cement and 70 ~ 100kg of steel to build[11]. Once in use, each building regularly consumes energy for heating, air conditioning, lighting, and other electric appliances.

Due to fast growing demand, primarily from the construction industry, cement and steel production have surged. Cement production grew from 210 million tons in 1990 to 2.42 billion tons in 2013 (about half of global output of the year). The iron and steel industry has seen similar development in the past. Annual steel production grew from 66 million tons in 1990 to 779 million tons in 2013.

Electricity demand has also surged since 1990, from 624 billion kWh in 1990 to 4976 billion kWh in 2012, an increase of 697% (9.88% pa). According to China Statistical Yearbook 2013, about 78% of the electricity power was thermal power, basically from coal. The rest were generated from hydro, nuclear, wind and solar photovoltaic (PV). Each kWh of electricity generated from coal, at a generation efficiency of 33%, emits about 1 kg of CO_2.

Led by growth from automotive and construction industries, as well as the power sector, fossil fuel consumption has soared, and so have emissions. However, due to fast economic growth, technology change, and effective government environmental policies, the intensity of carbon emissions per unit GDP has dropped considerably, from 5.55 ton per 10, 000RMB (2005 constant price) in 1990 to 3.05 in 2005. In 2013, it dropped to below 2.06. Historical trends of China's fossil fuel demand, its carbon emissions, and the intensity are shown in the Table 1, in which mt means million tons.

Table 1 Historical fossil fuel consumptions, emissions, and carbon intensity

	1990	2005	2013
Coal demand in mt TCE	752.12	1,552.55	2475
Petroleum demand in mt	114.86	325.35	690
Gas demand in billion cubic meter	15.25	46.76	217.5
Fossil fuel and cement industries CO_2 emission in mt	2,404.48	5630.4	8289.2
Real GDP (Billion, 2005 constant price)	0.433	1.849	4.029
CO_2 intensity per unit GDP	5.55	3.05	2.06

3 Scenario analysis

3.1 BAU scenario

In the BAU scenario, it is assumed that, from 2012 to 2030, world peace is generally maintained; imports of oil, minerals, other raw materials, and food, are available to China, although they may be more expensive; China maintains its domestic social stability; no major natural catastrophes happen in China.

It is also assumed that China will continue its energy efficient and conservation policies, such as: lowering taxes on smaller engine cars and raising taxes on larger ones, replacing smaller, inefficient plants with larger, efficient ones in cement, steel, and chemical (including chemical fertilizer) industries, and implementing the existing targets for alternative energy sources[11-13] as shown in Table 2.

Table 2 Alternative energy capacity targets

	Unit	2020	2030
Wind	MW	150,000	300,000
Solar PV	MW	20,000	50,000
Hydro	MW	320,000	400,000
Nuclear	MW	70,000	200,000
Biofuel	Ton	2,000,000	4,000,000

In the BAU scenario, real GDP will continue to grow quite fast, from 26.85 trillion Yuan to 92.74 trillion from 2010 to 2030, growing about 5.82% annually at medium speed. The continued high growth is due to the Chinese culture of high saving rate, strong drive for material wealth, and emphasis on children's education and technology innovation. But the real GDP growth rate could be lower in the future due to slower labour supply growth and economic structure shift from resource intensive industrial production to services. Total population will continue to grow slowly and reach 1.45 billion at 2030 with total fertility staying below 1.7. This growth, despite a low fertility rate, is due to longer life expectancy and the population structure where women of fertile ages are still a large proportion of the population.

CO_2 emissions from fossil fuels and cement will reach the peak at 2027 about 11.57 billion tons, and about 11.43 at 2030. Carbon intensity per real GDP drops from 3.05 in 2005 to 1.63 in 2020, a drop of 46.70%.

Demand for fossil fuels will continue to grow, especially oil. Oil demand will more than double, from 325 million tons in 2005 to 855 million tons in 2030, while oil import demand in 2030 will be over four times as high as in 2005. This is due to flat or even declining domestic oil production at about 200 million tons a year.

By 2030, electricity from alternative sources will be substantial, totalling 3,569 billion kWh, accounting for over 34.78% of all the electricity generated compared to 18.53% in 2005. Total electric power generation will reach 10,261 billion kWh.

Investments on alternative energy sources from 2011 to 2030 will be 7.79 trillion yuan (nominal price), indicating that the targets in Table 2 are achievable. Construction and operations of these sources will create one to three million jobs.

A detailed comparison of the BAU scenario results with other scenarios is given in Table 3.

3.2 Technology scenario

The technology scenario (TECH) illustrates the results of the following policy choices:

(1) Increasing the capacities of wind, solar PV, biofuel, and nuclear energy sources to a level 50% higher than the BAU scenario in 2030, and their investment costs are taken into account.

(2) Increasing average vehicle fuel efficiency, measured in kilometres per litter of fuel, from about 7.5 km/litter in 2010 to 11 km/litter in 2030 (in BAU, it is 10 km/liter in 2030);

(3) Assuring that energy efficient technologies in cement and steel production will progress faster, reducing energy demand per unit of production by 0.3% annually for cement (compared to 0.2% in BAU), and 0.3% for steel (compared to 0.2% in BAU). It is assumed that investments in energy (fuel) efficiency technologies will be paid back by the resulting energy savings.

With the policy changes in this scenario, electric power generated by fossil fuels (primarily coal) in 2030 will decrease from 6,696 billion kWh in BAU to 4,962 billion kWh, and electricity from alternative sources will increase to 51.63% of all the electricity generated. Oil consumption in 2030 will decrease from 8.55mt in BAU to 8.12mt. Energy consumption in cement and steel industries will also decrease. Total CO_2 emissions from fossil fuels and cement in 2030 will decrease from 11.43 billion tons in BAU to 10.03 billion tons in TECH. Carbon intensity per unit of real GDP in 2020 will decrease from 1.63 in BAU to 1.51, a 50.49% reduction from the 2005 level. The cumulative investment on renewable and nuclear energy from 2015 to 2030 will be 97.96 trillion RMB and 1.5 times of BAU scenario.

Table 3 Scenario comparison for 2030

		Unit	BAU	TECH	BEHAVIOR	TECH&BEHA
	Economy:					
1	real GDP	Trillion Yuan2000/Yr	57.32	57.32	57.13	57.13
	Fossil fuels and CO_2 emissions:					
2	total primary energy demand	MTCE/Yr	5503	5439	5223	5163
3	coal demand in coal equivalent	MTCE/Yr	2934	2456	2752	2254
4	petroleum demand	MT/Yr	855	812	800	759
5	net petroleum import	MT/Yr	643	597	567	524
6	fossil fuel and cement CO_2 emission	Bn Ton/Yr	11.43	10.03	10.70	9.26
7	carbon intensity	TonCO_2/2005RMB	1.05	0.93	0.97	0.84
	Electricity:					
8	total electricity demand	Bn kWh/Yr	9702	9695	9386	9377
9	electricity from fossil fuels	Bn kWh/Yr	6696	4962	6362	4552
	Electricity from alternative sources:					
10	electricity from wind	Bn kWh/Yr	532	796	532	797
11	electricity from solar PV	Bn kWh/Yr	78	117	78	117
12	electricity from hydro	Bn kWh/Yr	1398	2018	1398	2085
13	electricity from nuclear	Bn kWh/Yr	1538	2342	1538	2347
14	non fossil fuel electricity share	%	34.77	51.63	35.94	54.12
15	Investment for renewable and nuclear	% of GDP	0.51	0.80	0.49	0.77
16	Employment for above sources	Persons	3568008	5304409	3566873	5091333
	Cement:					
17	cement demand	Million Ton/Yr	1413	1413	1253	1253
18	cement energy consumption	MTCE/Yr	148	148	131	131
19	cement CO_2 emission	Million Ton/Yr	681	681	603	603
	Iron and steel:					
20	steel demand	Million Ton/Yr	739	739	679	678
21	iron steel energy consumption	MTCE/Yr	414	412	384	382
22	iron steel CO_2 emission	Million Ton/Yr	116	115	107	106

3.3 Behaviour scenario

The behaviour scenario (BEHAVIOR) includes government tax and price policies, together with public education programs, which cause behaviour changes towards more sustainable living. Specifically, the policy choices include:

(1) Electricity and oil retail prices will be raised through progressive pricing or higher taxes. The electricity average price will rise by 50%, and oil by 100%, compared to BAU in 2030 (In BAU, the real prices of electricity and crude oil are assumed constant over time); and

(2) The government will use a real estate property tax (currently there is none) and other tax/price means to encourage smaller but better residential living area per habitant. Urban per capita living area has more than doubled since 1990, to 32.9 square meters in 2012, and rural from 17.8 to 37.1 square meters. In this scenario, it is assumed that the tax changes will result in 40 square meters in 2030 at urban and rural, compared to 45 square meters in BAU.

With this scenario, cement and steel demand will be reduced substantially, and so will electricity and oil consumption due to both the energy tax increase and the reduction in cement and steel production. As a result, CO_2 emissions from fossil fuels and cement in 2030 will decrease to 10.70 billion tons, and reach the emission peak at 2026, both between BAU and TECH. Carbon intensity per unit of real GDP in 2020 will decrease to 1.55, a 49.26% reduction from the 2005 level.

3.4 TECH&BEHA scenario

This scenario is the combination of all the policy choices from the above two scenarios: TECH and BEHAVIOR. CO_2 emissions will be further reduced to 9.26 billion tons in 2030 and reach the peak at 2020. The carbon intensity will be 1.45 in 2020, 52.44% below the 2005 level, far beyond the 40% ~45% target set by the Chinese government.

3.5 Comparison of scenarios

Table 3 lists the values of major indicators for the four scenarios in the year 2030. The indicators are grouped into the following categories: economy, fossil fuels and CO_2 emissions, electricity, electricity from alternative sources, land, cement, and iron and steel.

Table 3 shows that Coal and Oil demand (Items 3 and 4) of the TECH&BEHA scenario are 23.18% and 11.22% lower than BAU, and CO_2 emissions (Item 6) is 19.02% lower. Oil import (Item 5) is 18.51% lower, which substantially improves China's energy security.

CO_2 emissions peak will reach at different year, and that of TECH&BEHA scenario is the earliest at 2020 and BAU at 2027. From 2015 to 2030 the cumulative CO_2 emissions reduction of TECH&BEHA scenario comparing to BAU will be 23.33 billion tons. Carbon intensity per GDP will continue to drop, as shown in Item 7 in Table 3.

Items 8 ~ 16 present the electric power demand and sources in each of the scenarios. Electricity from renewable and nuclear energy will account for 51.46% of all electricity generated in the TECH&BEHA scenario, and the required investment is about 0.77% of GDP in 2030, the cumulative investment on renewable and nuclear energy from 2015 to 2030 is about 102.4 trillion RMB under TECH&BEHA scenario comparing to 67.33 trillion RMB of BAU.

Items 17 ~ 22 show that with the TECH&BEHA scenario, cement and steel demands in 2030 will be 8% ~ 12% lower than the BAU scenario, which will be a major contributor to the substantial reduction in carbon emissions.

The TECH&BEHA scenario policies result in a lower real GDP (0.33% lower) than the BAU (Item 1 in Table 3). But still, this GDP growth is substantial. This slower GDP growth is partly due to higher electricity and oil prices; partly due to higher investments in alternative energy sources, which takes away investments in other areas; and partly due to slower growth of residence housing construction.

The slower GDP growth with the TECH&BEHA scenario could be underestimate, as residences become smaller and cost less, people will spend more on other things, so there is a shift in demand, which could boost GDP growth. Other factors, such as higher government revenues due to higher energy taxes and reduced oil import, could also contribute positively to GDP growth as the government could lower other taxes to increase private demand, or fund additional productive investment. These factors have not been included in the model, but could be added in our next phase of work.

Another interesting fact is that the Chinese Government has lowered its GDP growth target for the next five year plan to 7%, emphasizing more the quality of GDP rather than the mere GDP quantity. One important aspect of this quality is the resource efficiency, which is related to carbon intensity. The recent monetary policy, such as interest rate increase and appreciation of the Chinese currency, may also slow down GDP growth compared to the BAU case.

4 Conclusions and policy recommendations

(1) The CO_2 emissions reduction targets of China are achievable, but those also require great effort to put in. China's carbon intensity reduction target of 40% ~45% during 2005 ~ 2020 is ambitious, but with a combination of policy measures, the target seems achievable, based on the above analysis. The target of reaching the peak of CO_2 emissions around 2030 is also achievable. Although achievable, it is still a challenging task that requires coordinated national efforts. The reason is first the law of diminishing returns, as China has already substantially improved its GDP carbon intensity in the last 20 years, such as by investing billions of dollars to replace smaller, inefficient cement and steel making facilities with larger, efficient ones. Any further efficiency increase will require more investment per unit of output. Second, many of these processes, such as making steel from iron ore, or producing cement from limestone, have theoretical thresholds of minimum energy requirement which could not be exceeded.

(2) China will be able to achieve more sustainable economic growth by marching on the path to green development. The path to green economic development can also have negative effects on GDP growth, but these negative factors can be controlled. TECH&BEHA scenario real GDP is just 0.33% lower than BAU, if we take into account environmental costs TECH&BEHA scenario will be more competitive. From 2015 to 2030 the cumulative CO_2 emissions reduction of TECH&BEHA scenario comparing to BAU will be 23.33 billion tons, the cumulative energy savings will be 3.73 billion tce.

(3) A collaborative improvement in policy portfolios is needed for CO_2 emissions reduction. (1) Establish progressive prices or taxes on electricity and water, which guarantees that the poor still have the same access to these basic services, while waste will be reduced. As a result, the government and its providers

(electricity and water companies) may have some extra income to improve these services and related infrastructure to invest in renewable energy sources, (2) Establish progressive real estate property taxes to encourage sustainable living. The additional tax revenues can be used to support economic housing for the low income households, which could also reduce the risk of a housing bubble, (3) Improve the building code to require more energy efficiency and building quality so that buildings last longer and require less energy. Better buildings could be more expensive and more valuable, which could contribute to higher GDP growth and national wealth. More expensive and valuable buildings could also encourage sustainable living, taking account of the quality of the per capita living area; Supporting greener vehicles with carefully planned infrastructure construction, as the aspiration of owning a vehicle grows rapidly in China. Since there is not enough domestic oil to power the vehicles, nor enough land for roads and parking places, citizens should also be encouraged to drive less and use alternative transportation;

(4) Raise the public awareness about how to live sustainably, including slower growth of living spaces, and more use of bicycles. China was used to be a "bicycle kingdom", however, the proportion of the public that uses bicycles as a means of daily transportation is decreasing sharply. In contrast, a significant amount of people in many European countries choose public transportation and bicycles.

(5) Identify and develop more green technologies that will help the country to achieve its development strategies. Technology is a powerful tool when it comes to enhancing the efficient use of energy and resources. The development of renewable energy technologies makes it possible for humanity to rid itself of its dependence on fossil energy. China has deployed plenty of green technologies within the outline of the national program for medium and long term scientific and Technological Development (2006 ~ 2020). It now needs to improve its technological innovation by treating enterprises as a mainstay. The direction for new policies should be market-oriented, and they need to employ the combined assets of industry and academic research. The focus should be on developing key common technologies that support green industry development.

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