ASSESSING FUTURE CARBON EMISSIONS FROM FOSSIL FUELS OF CHINA

ABSTRACT

The Chinese government has set an ambitious target to reduce the intensity of carbon emissions per unit GDP by 40 – 45% during 2005 to 2020. 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, and food security, and illustrating 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 the future carbon emissions: 1) the BAU (business as usual) scenario which shows the likely results of continuing current policies; 2) the TECH (technology) scenario, which shows the effects of more investment in renewable energy sources and promoting more energy efficient technologies; 3) the BEHAVIOR scenario, which shows 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 scenario results show that the 40 - 45% carbon emission reduction for the period 2005 – 2020 is achievable.

Keywords: carbon emissions, GDP carbon intensity, sustainable development

1. Introduction

The Chinese government has set an ambitious target to reduce the intensity of carbon emissions per unit of its GDP by 40 – 45% during 2005 to 2020. This is probably the most important decision made by the Chinese government in recent years towards sustainable development. Its target to reduce emissions intensity is on par with those implicit in the US and EU targets (Stern 2010). How will China achieve this target? 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 (Cai et al. 2008; Cai et al. 2010; Wang and Watson 2010). What are the implications of trying to achieve this proposed target for the country's general development goals? The T21 China model can demonstrate the results of various possible policy combinations used specifically to achieve this target and show how effects of these policies relate to other goals.

The T21 national development and planning model is a system dynamics based tool that has been applied to over 20 countries (Sterman 1988; Barney et al. 1999a； Qu et al. 2000; Bassi et al 2009; Bassi and Shilling 2010; Qu et al 2011). The T21 China 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 (Barney et al 1999b; Qu et al. 2005; Qu et al. 2009; Tong et al. 2009). It integrates population, agriculture, land, water, industry, services, employment, income distribution, energy demand and supply, and other social, environmental, and economic sectors into a single framework to generate coherent, long-term scenarios. Its transparent structure and interactive user-interface enables all stakeholders to engage in constructive dialogue about policy options and understand how the various results are achieved. The model generates scenario results for any set of policies and allows comparison of the different results to help reach better decisions. The focus of this paper is on policies that have substantial impacts on carbon emissions from fossil fuels.

The general overview of the causal relationships of CO_2 emission from fossil fuels is represented by the arrows, in Figure 1, where fossil fuel consumption (in bold) 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. (These are shown in the figure: other factors are not shown here.) Transportation is determined by both overall production (related to GDP) and population size. Similarly electricity generation is also driven by production levels, per capita income, and population size. Real GDP and population (in 0 – 80+ age cohorts) are endogenously modelled in T21. Fossil fuel consumption in each of these sectors determines its CO_2 emissions, which in turn affects health and life expectancy. Life expectancy further affects production and total population, thus forming some of the important feedback loops.

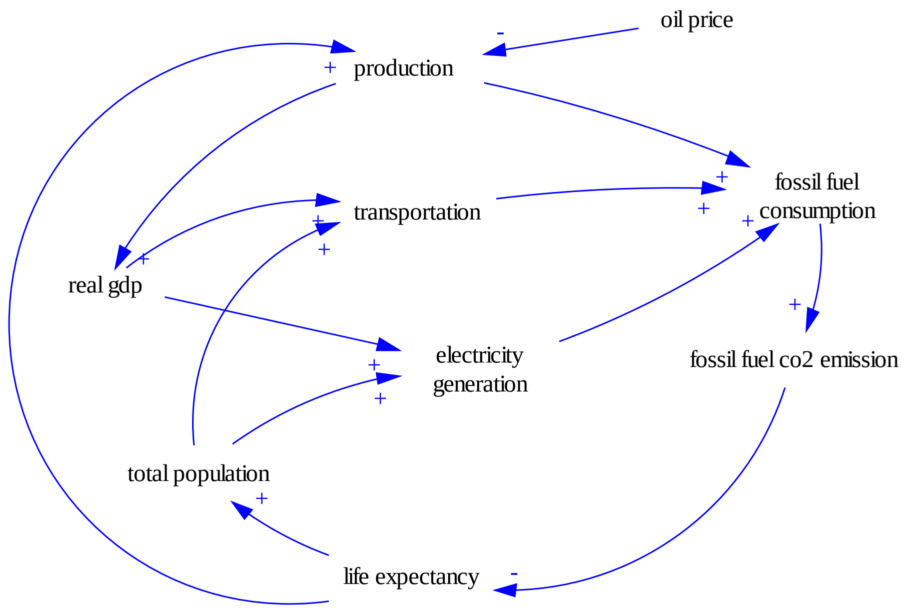

Figure 1: General causal relations of fossil fuel CO_2 emission

Actual causal relations in the T21 model are much more detailed and specifically developed for China. In Figure 2, an example for 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 – 2008 has consumed about 99% of cement production. Domestic demand is determined by activity in the five main sectors using cement: urban residential construction, commercial construction, rural residential construction, rail and roads, and other sources of 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 per square meter cement demand. During 1990 – 2008, demand from urban residential construction accounted for 30 – 40% of domestic cement demand. Future urban residential construction cement demand depends primarily on how much larger urban per capita residential space will grow from the current level of about 30 square meters and the rate of urban population growth. The variables enclosed by <> are computed in other sectors of the model and used in this sector. Cement demand computed in this sector is an input into other sectors to determine how much is produced (by either rotary or vertical kilns) to meet this demand. This will then determine how much energy (primarily coal and electricity) will be consumed and how much CO_2 will be emitted for cement production related to urban construction. A similar set of relations are used for the steel used in urban construction. Some additional fossil fuels will be used by the construction machinery in building the housing, increasing the CO_2 emissions from urban constriction.

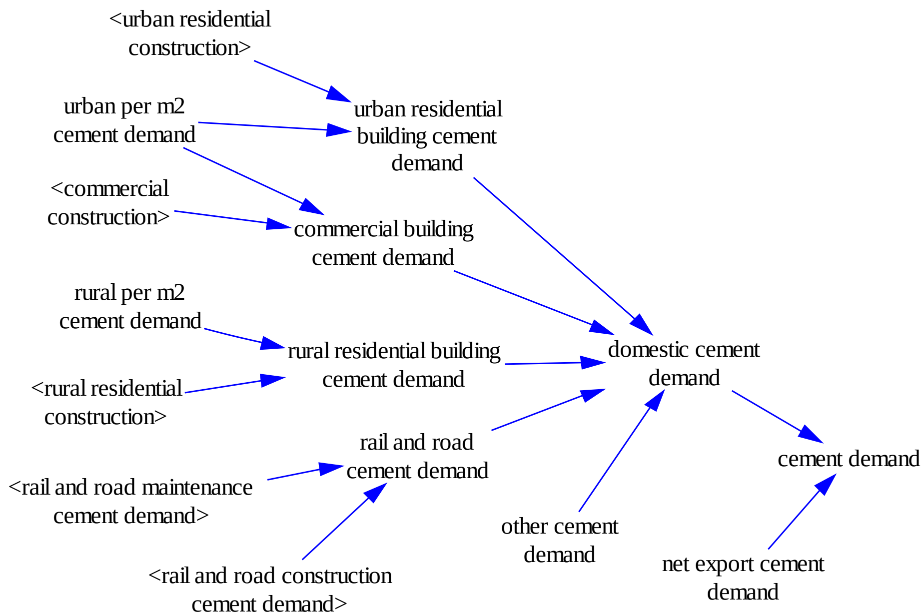

Figure 2: The actual cement demand sector in T21 China

Chapter 2 presents the historical trends since 1990 related to carbon emissions. Chapter 3 introduces the BAU (business as usual) scenario from the T21 China model, showing the likely outcomes of continuing current policies. It then explores three possible policy sets: 1) technology, 2) behavior changes due to tax changes and price-awareness, and 3) the combination of these two to deal with the challenges faced in reducing carbon emissions. Chapter 3 then compares the major results of all these four scenarios and indicates how a well designed combination of choices can help China achieve its strategic target. Chapter 4 presents a summary and proposes policy choices.

2. Historical trends as they related to carbon emissions

Since its economic reform and open door policy started about 30 years ago, China has experienced explosive economic growth. Between 1990 and 2008, total population increased about 16%, from 1.15 billion to 1.33 billion (due to its one child policy, total fertility rate has remained at about 1.67), while real GDP increased 435% (9.8% pa). According to China Statistical Yearbook 2009, per capita GDP in 2008 reached 20,000 RMB, almost 3,000 US dollars.

With this fast growth in income and wealth, living standard and consumption patterns have undergone dramatic change, which has direct impacts on carbon emissions. A brief description of some of the main sources of CO2 emissions is presented below.

In 2010, vehicle sales in China exceeded 18 million, and for two consecutive years (2009 and 2010), China was the world's largest vehicle market. To manufacture a car requires 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 29 square meters in 2008 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 concrete and steel. Each square meter of these high rise buildings needs 300 - 400 kg of cement and 70 – 100 kg of steel to build (Jiang 2006). 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 1.35 billion tons in 2007 (about half of global output of the year), a 643% growth (11.5% pa). Although China has made considerable efforts to reduce the energy use per unit of cement production, reducing the energy consumption per ton of cement from 0.195 Tce (Ton coal equivalent) in 1990 to 0.137 Tce in 2007 (the world's best practice is about 0.11 Tce per ton cement), total annual energy use in cement production has climbed from 40 Mtce (Million ton coal equivalent) in 1990 to 185 Mtce in 2007. The chemical process of turning limestone into calcium oxide used in cement production also releases CO_2. Total CO_2 emissions from cement production grew from 209 million tons in 1990 to 1 billion tons in 2008 (Zhou 2007).

The iron and steel industry has seen similar development in the past. Annual steel production grew from 66 million tons in 1990 to 489 million tons in 2007, a 732% growth (12.4% pa). Due to technological progress and implementation of the government's policy of replacing smaller furnaces with larger, more efficient ones, the energy use per ton of steel dropped from 1.44 Tce in 1990 to 0.69 Tce in 2007, a reduction of over 50%. But due to huge production increase, total energy use in steel production still increased a lot, from 93 Mtce a year in 1990 to 327 Mtce a year in 2007. CO_2 emissions grew proportionally, from 259 million tons a year in 1990 to 953 million tons a year in 2008 (Wang et al. 2007) for steel.

Electricity demand has also surged since 1990, from 624 billion KWH in 1990 to 3,310 billion KWH in 2008, an increase of 430%. According to China Statistical Yearbook 2009, about 83% of the electricity power was generated from fossil fuels in 2008, 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. For the year 2008, coal power generation of 2,747 billion KWH (83% of 3,310 billion KWH) created 2.747 billion tons of CO_2 emission, accounting for over 40% of national CO_2 emissions from fossil fuels.

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 (measured in kg of CO_2) per unit GDP has dropped considerably, from 0.65 kg per Yuan (all currency units are constant 2000 value based) in 1990 to 0.34 kg per Yuan in 2005, a reduction of about 48%. In 2010, it is estimated that this intensity dropped to below 0.32. Historical trends of fossil fuel demand, its carbon emissions, and the intensity are shown in the following table, in which mt means million tons.

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

	1990	2005	2008
Coal demand in mt TCE	752.12	1,552.55	1,973.98
Petroleum demand in mt	114.86	325.35	401.23
Gas demand in billion cubic meter	15.25	46.76	64.2
Fossil fuel CO_2 emission in mt	2,404.48	5,358.89	6,611.66
Carbon intensity per unit GDP	0.65	0.34	0.32

3. Scenario analysis

3.1. BAU scenario

In the BAU scenario, it is assumed that, from 2008 to 2020, world peace is generally maintained; imports of oil, minerals, other raw materials, and food, are available to China, although they could be more expensive; China maintains its domestic social stability; no major natural catastrophes happen in China; and China continues its one child family planning policy.

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, more efficient ones in cement, steel, and chemical (including chemical fertilizer) industries; and implementing the existing targets for alternative energy sources (Li and Gao 2008; Li and Wang 2008; Xu et al. 2004) as shown in Table 2.

Table 2: Alternative energy capacity targets

	Unit	2010	2020
Wind	MW	10,000	70,000
Solar PV	MW	300	5,900
Hydro	MW	190,000	310,000
Nuclear	MW	19,380	60,000

In the BAU scenario, real GDP will continue to grow quite fast, from 15.7 trillion Yuan to 44.8 trillion from 2005 to 2020, growing at 8 – 10% annually during the first 5 years or so, and decreasing to about 6%, with an average rate of 7.2% during the period. This is due to the Chinese culture of having a high saving rate, strong drive for material wealth, and emphasis on children's education. Total population will continue to grow slowly, with total fertility stays below 1.7. This growth, despite a low fertility rate, is due to longer life expectancy, and the population structure that women of fertile ages are of a large proportion.

CO_2 emissions from fossil fuels will continue to rise from 5.36 billion tons in 2005 to 9.88 billion tons in 2020. However, carbon intensity per real GDP in kg CO_2 per Yuan (year 2000 base), will drop from 0.34 in 2005 to 0.22 in 2020, a drop of 35%.

Demand for fossil fuels will continue to grow, especially oil. Oil demand will more than double, from 325 million tons in 2005 to 822 million tons in 2020, while oil import demand in 2020 will be over four times as big as in 2005. This is due to flat or even declining domestic oil production at below 200 million tons a year.

By 2020, electricity from alternative, primarily renewable, sources will be substantial, totalling 1,803 billion KWH, accounting for over 25.5% of all the electricity generated. Total electric power generation will reach 7,037 billion KWH.

Investments in the alternative energy sources as a share of GDP will be below 1%, indicating that the targets in Table 2 are achievable. Construction and operations of these sources will create one to two million jobs, which are less than 0.4% of total national employment.

A detailed comparison of the BAU scenario with other scenarios is given in Table 3. All of the scenarios use the actual historical data from 2005 to 2010, and then the model generates the projections from 2010 to 2020 to show how things will further develop. This is done to illustrate how further policies instituted in 2011 will shift the development path to make more progress on reducing CO_2 emissions by 2020, compared to BAU, and achieve the government's goal. They also show some of the other effects that will occur between 2011 and 2020 compared to continuing BAU, as discussed below.

3.2. Technology scenario

The technology scenario (TECH) includes the following policy options put in place and activated:

A. Capacities of wind, solar PV, and nuclear energy sources will be 50% higher than the BAU scenario in 2020, and their investment costs are taken into account.

B. Average vehicle fuel efficiency, measured in kilometers per liter of oil, will increase from about 7 now to 11 in 2020 (in BAU, it is 8 km/liter in 2020); and

C. Energy efficient technologies in cement and steel production will progress faster, reducing unit production energy demand by 1.5% annually for cement (compared to 1% in BAU), and 2% for steel (compared to 1.5% in BAU). It is assumed that investments in energy (fuel) efficiency technologies will be paid back by future energy savings.

With this scenario, electric power generated by fossil fuels (primarily coal) will decrease from 5,243 billion KWH in BAU to 4,823 billion KWH in 2020, and the electricity from alternative sources will increase to 30% of all the electricity generated. Oil consumption in 2020 will decrease from 8.22 mt in BAU to 7 mt in TECH. Energy consumptions in cement and steel industries will also decrease. CO_2 emissions from fossil fuels in 2020 will decrease from 9.88 billion tons in BAU to 9.06 billion tons in TECH. Carbon intensity per real GDP in 2020 will decrease from 0.22 in BAU to 0.206 in TECH, a 39.5% reduction from the 2005 level.

3.3. Behaviour scenario

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

A. 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 2020 (In BAU, the real prices of electricity and crude oil are assumed constant over time); and

B. 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. Per capita living area has more than doubled since 1990, to 29 square meters in 2008. In this scenario, it will be 37 square meters in 2020 in BEHA, compared to 44 square meters in BAU.

With this scenario, cement and steel demand will be reduced substantially, and so will electricity and oil consumption. As a result, CO_2 emissions from fossil fuels in 2020 will decrease to 9.04 billion tons in BEHA compared to 9.88 billion tons in BAU and 9.06 billion tons in TECH. Carbon intensity per real GDP in 2020 will decrease to 0.215, a 37% reduction from the 2005 level, compared to .22 in BAU and .206 in TECH.

3.4. TECH&BEHA scenario

This scenario (TECH&BEHA) is the combination of all the policy choices from the above two scenarios: TECH and BEHA. CO_2 emissions and carbon intensity will be further reduced to 8.34 billion and 0.20 in 2020. Carbon intensity will be 41% below the 2005 level, reaching 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 2020. 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: Scenario comparison for 2020

		Unit	BAU	TECH	BEHAVIOR	TECH&BEHA
	Economy:					
1	real GDP	Trillion Yuan2000/Yr	44.8	44.0	42.1	41.4
	Fossil fuels and CO_2 emissions:					
2	coal demand in coal equivalent	MTCE/Yr	2,693	2,527	2,451	2,299
3	petroleum demand	MT/Yr	822	700	756	645
4	net petroleum import	MT/Yr	639	517	555	444
5	fossil fuel CO_2 emission	Bn Ton/Yr	9.88	9.06	9.04	8.28
6	carbon intensity	$KgCO_2$/Yuan2000	0.2204	0.2061	0.2148	0.2001
7	carbon intensity reduction	compared to 2005	35.17%	39.37%	36.81%	41.14%
	Electricity:					
8	total electricity demand	Bn KWH/Yr	7,037	6,925	6,548	6,462
9	electricity from fossil fuels	Bn KWH/Yr	5,234	4,823	4,745	4,360
	Electricity from alternative sources:					
10	electricity from wind	Bn KWH/Yr	115.34	172.44	115.34	172.44
11	electricity from solar PV	Bn KWH/Yr	7.13	10.70	7.13	10.70

12	electricity from hydro	Bn KWH/Yr	1,197	1,197	1,197	1,197
13	electricity from nuclear	Bn KWH/Yr	483.64	722.44	483.64	722.44
14	Electricity from above sources	%	25.62%	30.36%	27.53%	32.53%
15	Investment for above sources	% of GDP	0.71%	1.05%	0.76%	1.12%
16	Employment for above sources	Persons	1,457,827	1,755,573	1,457,827	1,755,573
	Land:					
17	Agriculture Land	Million Hectare	116.8	116.8	117.4	117.4
18	Residential And Industrial Land	Million Hectare	30.37	30.37	29.42	29.42
	Cement:					
19	cement demand	Million Ton/Yr	1,320	1310	992	991
20	cement energy consumption	MTCE/Yr	141	136	108	104
21	cement CO_2 emission	Million Ton/Yr	826	814	627	617
	Iron and steel:					
22	steel demand	Million Ton/Yr	628	622	505	500
23	iron steel energy consumption	MTCE/Yr	261	241	205	190
24	iron steel CO_2 emission	Million Ton/Yr	730	674	574	530

Table 3 shows that Coal and Oil demand (Items 2 and 3) of the TECH&BEHA scenario are 15% and 22% lower than BAU, and CO_2 emissions (Item 5) is 16% lower. Oil import (Item 4) is 30% lower, which substantially improves China's energy security.

CO_2 emissions will continue to rise, from 5.36 billion tons in 2005 (and 6.6 billion tons in 2008) to 9.88 billion tons for BAU and 8.29 billion tons for TECH&BEHA in 2020. However, carbon intensity per GDP unit will be reduced to 0.22 in BAU, (35% below the 2005 level) and to 0.20 in TECH&BEHA, (41% below the 2005 level), as shown in Items 6 an 7 in Table 3. The combination of TECH and BEHA policies enables the China to reach the .20 carbon intensity target by 2020.

Items 8 – 16 presents the electric power demand and sources in each of the scenarios. Electricity from alternative sources (including nuclear) will account for 32.5% of all electricity generated in the TECH&BEHA scenario, and the required investment is about 1.12% of GDP, indicating this much capacity in alternative energy sources is affordable for China.

In terms of sustainable development, one huge challenge China faces is food security. To reduce its dependence on food imports, China must protect its precious agriculture land. Item 17 in Table 3 shows that by encouraging sustainable living, China will have more agriculture land in 2020 than the BAU scenario, which will facilitate more food production than in BAU.

Items 19 – 24 show that with the TECH&BEHA scenario, cement and steel demands in 2020 will be 20 – 25% lower than the BAU scenario, which will be a major contributor to the substantial reduction in carbon emissions.

The TECH&BEHA scenario generates a lower real GDP (9% lower) than the BAU (Item 1 in Table 3). But still, this GDP growth is substantial, more than double the 2008 real GDP value. 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 demand.

The slower GDP growth with the TECH&BEHA scenario could be an underestimate, as residences become smaller and cost less, people will have more to spend on other things, so there is a shift in demand, which could boost GDP growth. Also the lower consumption of cement and steel in housing construction would lower measured GDP in those sectors although there is not a reduced availability of housing units based on cement and steel. Other factors, such as higher government revenues due to higher energy taxes, and reduced oil import, could also contribute positively to GDP growth. These factors have not been included in the model, but could be added in our next phase of work, along with the creation of more jobs fro the shifts in activities.

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. Reduced CO_2 emissions will also have positive benefits on health and other social factors, which do improve welfare, though such improvements are not reflected in the GDP.

Some literatures have put forth the argument that investments in green economy activities can actually accelerate GDP growth. We believe this could be true if the right green technologies are selected for a specific country. This could be applied to China, and more work needs to be done to identify the green technologies that will add to the baseline GDP growth rates. But we believe that the statement that any green investments will accelerate GDP growth in any countries for both short term and long term is premature. Much more research and tests are needed to support this statement.

4. Summary and policy recommendations

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.

Although achievable, it is still a challenging task that requires coordinated national efforts. The main reasons are: First, the law of diminishing returns, China has already substantially improved its GDP carbon intensity in the last 20 years, such as by investing billions of dollars to replace the smaller, inefficient cement and steel making facilities with larger, efficient ones. So 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.

Reducing carbon emissions is an important sustainable development strategy for China. So are some other strategies, including maintaining GDP growth, reducing unemployment and poverty, improving energy security and food security, and keeping social stability. Chinese policy makers, development institutions, and experts are working hard to understand how to deal with the challenges they will have to face in the future, and they have made big achievements so far. In doing their work, each of them has a specific position that focuses on progress in their own area, and they may well not agree with each other on their position. It is not easy for people with different positions to exchange their ideas and debate about the right policies to choose. The integrated T21 model significantly helps people with different backgrounds and responsibilities communicate and work together to formulate the best long-term policies to achieve a more sustainable future for China as a whole by taking account of the cross-sector interactions, supporting positive synergies, and mitigating negative feedbacks.

Some other factors not included in this paper could have substantial impact on carbon reduction strategy and other important strategies. Examples of such factors include population growth, food production, and employment. Each of the factors includes multiple sub-factors, such as with population, there are many factors, including urban population size, total fertility rate, and life expectancy at birth. T21 includes these factors endogenously so that policy analysis can be expanded when needed.

Based on the initial T21 results and analysis, and the personal observations of the authors, it seems that the following points may be especially helpful for China to achieve the results of the TECH&BRHA scenario:

A. Establish progressive prices or taxes on electricity and water. This guarantees that the poor would still have the same access to these basic services, while waste will be reduced. The government and the providers (electricity and water companies) may have as a result some extra income to improve these services and the related infrastructure and to invest in renewables;

B. Establish progressive real estate property taxes, to encourage slower growth in housing size and more sustainable living. The additional tax revenues can be used to support economic housing for the low income households. This would also reduce the risk of a housing bubble;
C. Improve the building code to require more energy efficiency and building quality so that buildings last longer and require less energy for heating and cooling. 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. In addition, the lower energy costs from higher efficiency would offset some of these higher building costs over time;
D. Increase tax on oil to reduce import dependence. Revenues from this tax can be used to subsidize alternative energy projects;
E. Support 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. They could also encourage more shift to vehicles power by natural gas, which has lower CO_2 emissions than gasoline and is becoming more available;
F. Raise the public awareness the need to live sustainably and how to do so, including slower growth of living spaces, and more use of bicycles;
G. Continue the one child per family policy for another period of time, and expand the rewarding system for parents who abide by this policy, especially in the rural areas. T21 China can be used to explore how long this period should be.
H. Identify and develop more green technologies that will help the country to achieve several or all of its development strategies.

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