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A dynamic low-carbon scenario analysis in case of Chongqing city

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Abstract

In this paper, a dynamic low-carbon model was developed to show a quantitative and consistent future snapshot. This study presents three scenarios for Chongqing's energy consumption and related CO_2 emissions up to 2020, which includes basic development scenario, macro-policy control development scenario and low carbon development scenario. It explains the crucial technologies for Chongqing city as it leaves a business-as-usual trajectory and embarks on a low carbon pathway. A major finding from the scenario analysis is that low carbon and energy-saving policies can dramatically improve Chongqing's position. Under the low carbon scenario, several suggestions for policy making are proposed. This dynamic low-carbon model would benefit from the allocation of decision-making powers in the areas of regulation, policy-making and planning for low carbon development.

Keywords: Low-carbon city, dynamic model, scenario analysis, Chongqing

1. Introduction

The transition to a low carbon economy poses an enormous challenge for the global urban system [1]. Several important questions have to be addressed to analyze the implications of this large scale transition from a global urban society: (1) what is the main driver behind this massive transition? (2) is energy requiring fewer resources per capita at a given level of services? (3) how dependent are cities on the fossil energy bonanza? (4) what are the greenhouse gas impacts of massive urbanization and industrialization? (5) can we define a set of typologies of patterns of low carbon cities that can be used to study low carbon

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development models at a transformational scale. It is essential to answer these questions in order to establish a link between different types of indicators covering different aspects of sustainability. In fact, there is already a vast literature of analysis dealing with the GHG emission of cities and thermodynamic analysis [2-8]. What is missing is an integrated approach capable of establishing a bridge across the three legs of sustainability: (i) economic viability; (ii) social desirability; and (iii) ecological compatibility.

In China, a series of GHG emission control objectives have been issued in Nov. 2009 to reduce the CO_2 emission per unit GDP in 2020 by 40%-50% percent compared to that of 2005, which is highlighted as the objective to be included in the overall medium and long-term plans for national economic and social development. To realize the mentioned objectives, it is necessary to transform the current economic development into a low-carbon one. Thus, the low-carbon development, characterized as a novel development mode with low energy consumption, low environmental pollution, and low emissions, is proposed under the context of global warming that is critically challenging and threatening the human life and development.

As one of the first batch of low-carbon economy demonstration cities, the low-carbon transition of energy industries is an important part of the low-carbon economy construction of Chongqing city. The energy industry is one of the six highest energy-intensive industries, producing a large proportion of the total CO_2 emission of Chongqing city. In addition, the transition may significantly promote the low-carbon development of the other industries, sectors and Chongqing city as a whole. Therefore, it is meaningful to conduct the low-carbon development research and explore the path to low-carbon economy construction.

The focus of this research is the energy industry of Chongqing city. Specifically, it is aimed to investigate the path and effects of the low-carbon transition of the energy industry. Referring to the low-carbon transition of the energy industry, this study tries to propose the major tasks and concrete suggestions for the decision-makers to establish the corresponding policies and regulations for the development of energy industry in Chongqing city.

2. Case study

2.1. Brief profile

Chongqing is a major city in Southwest China and one of the five national central cities of the China. Due to its rapid urbanization, Chongqing has transformed into a vital industrial area in western China.. Although Chongqing's industries have now diversified, unlike eastern China, its export sector is small due to its inland location. Instead, factories producing local-oriented consumer goods such as processed food, autos, chemicals, textiles, machinery and electronics are common. Recently, there has been a drive to move up the value chain by shifting towards hi-tech and knowledge-intensive industries, resulting in new development zones such as the Chongqing New North Zone.

Chongqing has experienced rapid growth by global standards in energy consumption and carbon emissions over the past 10 years. Since 2005 the annual increase in electricity has been in the order of 10%. Overall energy consumption in 2007 was 24 million tons of standard coal equivalent, of which over three-quarters was consumed by the industrial sector and only 15% by the residential sector and 4% by transport.

Fig. 1. The location of Chongqing

2.2. The status quo of Chongqing energy industry

(1) Coal industry

Coal industry is not only the major sector of energy production, but also an intensive industry with high consumption of resources, energy and water in Chongqing. There are 795 coal enterprises in Chongqing 2007, with the annual production capacity of 41,960,000 tons. A total of 19,738,300 tons of raw coal are transferred from outside the city, mainly from the neighboring provinces, i.e., Guizhou, Shaanxi and Sichuan.

(2) Power industry

Electric Power Industry of Chongqing is impacted by the primary energy resource constraints, and the development level is relatively low. Therefore, the electric network of Chongqing is a typical receiving-terminal grid network. Up to October 2009, the city occupies a total of 11,281,100 kW generating capacity (including corporate-owned power), of which installed capacity of hydropower is 4,398,800 kW, thermal power installed capacity is 6,820,700 kW, and new energy 30,800 kW.

(3) Natural gas industry

In recent years, with the demand for natural gas growing rapidly in Chongqing, the main city is basically propagated with residential natural gas. A large number of industrial enterprises use natural gas as feedstock or fuel, and CNG cars develop rapidly. In this way, natural gas has become an important energy support for economic development in Chongqing. In 2007, 7.2 billion m^3 marketable natural gas have been produced within the administrative region of Chongqing. 39 districts and counties of

Chongqing except Wuxi County are using natural gas; in 2008, the number of urban residents using natural gas have reached 270.

(4) Renewable resource industry

There are a total of 529 biogas projects (including the new 175 large biogas projects), the total volume of which is 42,300 m^3.

Solar energy utilization rate in Chongqing is around 4%, of which Nanchuan District uses most. Other districts like Jiangjin, Qijiang, Yongchuan, Rongchang, Wanzhou have also made good use of it. The water heaters in these places are mainly solar-based, with electricity and heating serve as a supplement.

At present, the production of wind power equipment in Chongqing is only conducted by the shipbuilding industry, (Chongqing) Sea Windpower Equipment Co., Ltd. In 2006, the company imported the 850 kilowatts fan technology from Germany, and cooperatively developed a 2-MW wind turbine. In 2007, the company completed the design by shaping innovation and prototype manufacturing, installation, implementation and power generation, and the localization rate is nearly 90%.

2.3. Model Scope and data collection

Figure 2 maps the research outline for this study. The energy consumption and CO_2 emission are divided into five stages: (1) primary industry, (2) secondary industry, (3) Tertiary industry, (4) Household consumption, and (5) Carbon sink.

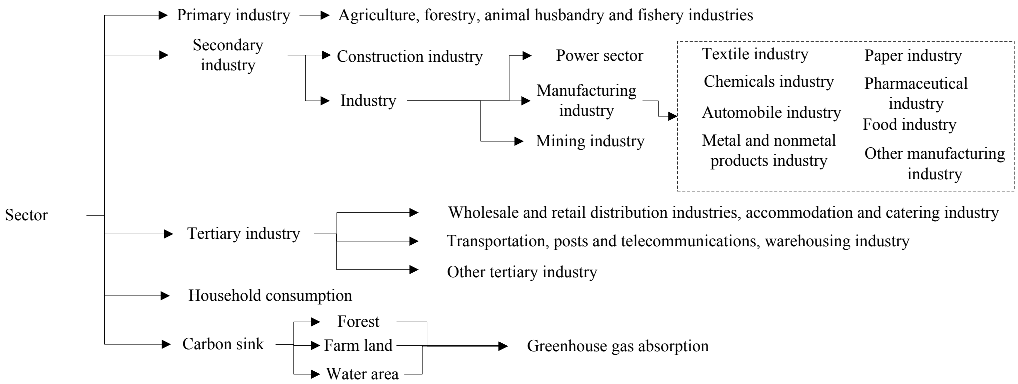


Fig. 2 Schematic representation of low carbon analysis system boundaries

The simulation is limited to energy consumption and related greenhouse gas emissions (only CO_2 is considered in this accounting). Data collection, emissions inventories and are based on the China Energy Statistical Yearbook (2004-2010), Chongqing Energy Balance Sheet (2004-2010) and Chongqing the annual industrial statistics reporting forms. A life-cycle assessment is employed as well to help identify the environmental benefits in more details, as emissions along the supply chain need to be considered. The timeframe for the analysis is 2007.

3. The main variables and subsystem division of urban energy dynamic model

3.1. The main variables of urban energy dynamic model

There are 194 parameters in the urban energy dynamic model, which includes stock, flow, variable and constant. We list the most important parameters as follows:

Table 1. The main variables of urban energy dynamic model

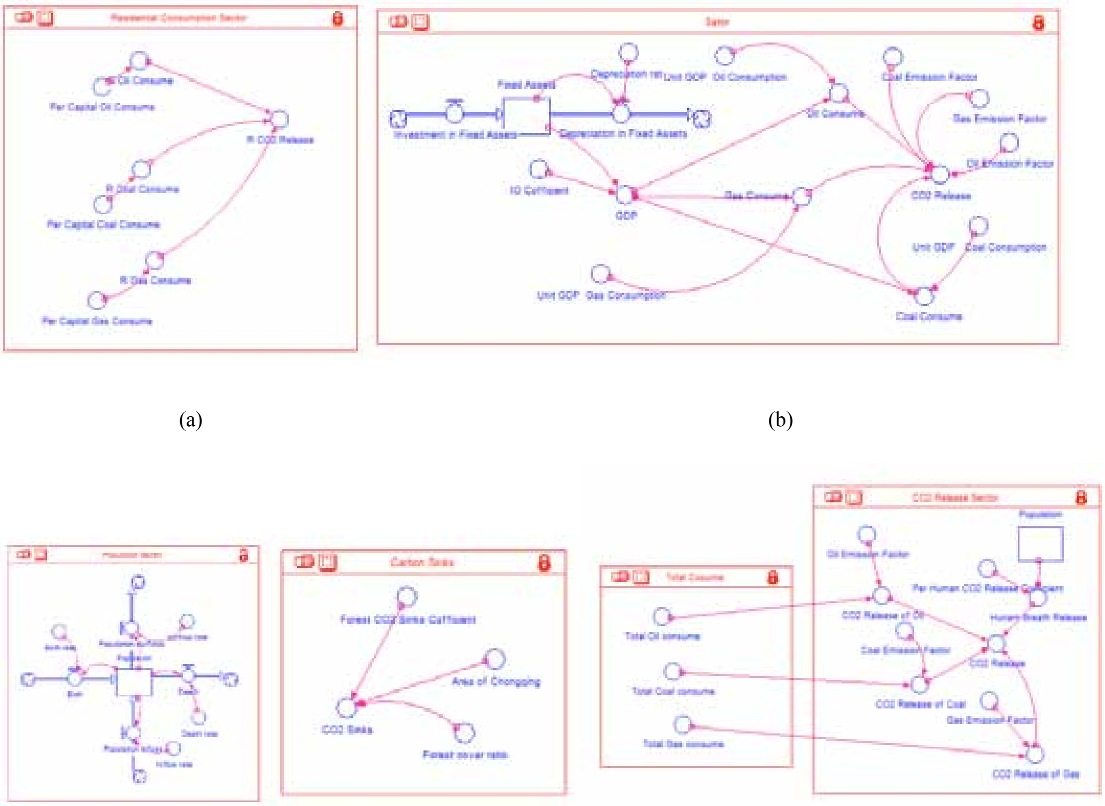
Parameters	Type	Units
Population	Stock	$\times 10^4$ population
Birth	Flow	$\times 10^4$ population
Death	Flow	$\times 10^4$ population
Population inflows	Flow	$\times 10^4$ population
Population outflows	Flow	$\times 10^4$ population
Birth rate	Variable	‰
Death rate	Variable	‰
Inflow rate	Variable	‰
outflow rate	Variable	‰
Fixed assets	Stock	$\times 10^4$ RMB
Depreciation in fixed assets	Flow	$\times 10^4$ RMB
Investment in fixed assets	Flow	$\times 10^4$ RMB
Depreciation rate	Variable	%
IO coefficient	Variable	%
Area of Chongqing	Constant	km^2
CO_2 sinks	Variable	t CO_2
Forest cover ratio	Variable	%
Forest CO_2 sinks coefficient	Variable	t CO_2/km^2/year
Years	Variable	year
Coal consume	Variable	$\times 10^4$ t
Total coal consume	Variable	$\times 10^4$ t
Coal emission factor	Variable	kg/GJ
CO_2 release of coal	Variable	t CO_2
Gas consume	Variable	$\times 10^8$ m^3

Gas emission factor	Variable	kg/GJ
CO_2 release of gas	Variable	t CO_2
Total gas consume	Variable	$\times 10^8$ m^3
Oil consume	Variable	$\times 10^4$ t
Oil emission factor	Variable	kg/GJ
CO_2 release of oil	Variable	t CO_2
Total oil consume	Variable	$\times 10^4$ t
Human breath ratio	Variable	t
CO_2 release	Variable	t CO_2
Per capital coal consume	Variable	$\times 10^4$ t /10^4 population
Per capital gas consume	Variable	$\times 10^8$ m^3/10^4 population
Per human CO_2 release coefficient	Variable	$\times 10^4$ t CO_2/population/year
Per capital Oil consume	Variable	$\times 10^4$ t /10^4 population
GDP	Variable	$\times 10^8$ RMB
Total GDP	Variable	$\times 10^8$ RMB
Unit GDP coal consumption	Variable	$\times 10^4$ t /10^8 RMB
Unit GDP gas consumption	Variable	$\times 10^8$ m^3/10^8 RMB
Unit GDP oil consumption	Variable	$\times 10^4$ t /10^8 RMB

3.2. Subsystem division of urban energy dynamic system

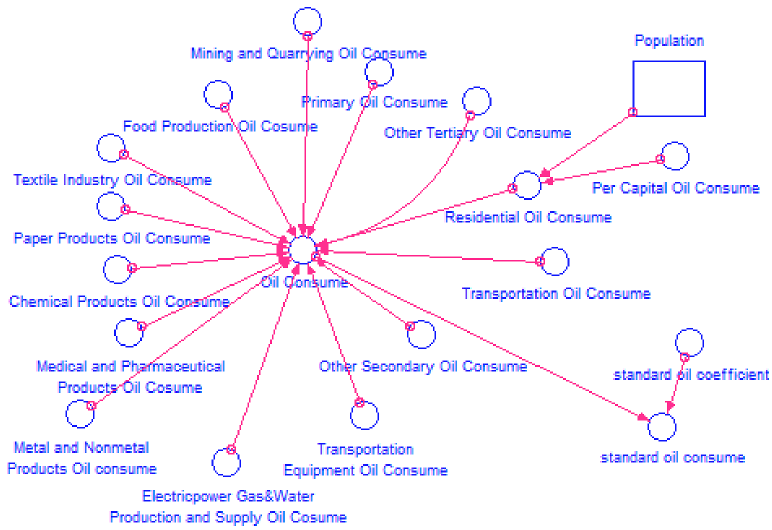
According to the environmental and economic characteristics of Chongqing, the dynamic low-carbon model could be divided into four subsystems, including socio-system, economic system, energy consumption system and greenhouse gas emissions system (the latter two subsystems include energy consumption system based on three major industries in Chongqing, and energy consumption system based on energy forms, domestic consumption system, greenhouse gas emissions system and carbon sinks). The total net CO_2 emissions equal the CO_2 emissions from energy consumption plus resident's emissions minus the net carbon sinks.

The model is written in STELLA 9 with a time-step of one stage in which runs span three stages. Based on the variables (in Table 1) and dynamic equations, the flow diagrams of each subsystem are shown in Fig. 2. In order to simulate the energy consumption and CO_2 emission in Chongqing, the internal interactions among all subsystems are established.



(a) (b)

(c) (d) (e)



(f)

Fig. 3. Subsystem division of urban energy dynamic system (a) residential consumption subsystem; (b) production sector; (c) population subsystem; (d) Carbon Sink subsystem; (e) CO2 emission system; (f) energy consumption (take oil as an example).

3.3. Parameter setting

The original operation parameters are set based on current data of Chongqing energy consumption and carbon emission parameters of IPCC report. The main statistical parameters are presented in Table 2:

Table 2 Parameter setting of urban CO_2 emission model

Items				Parameters and equation
Population*				Birth rate = 10.76‰
				Mortality rate = 6.19‰
				Emigration rate: y = 0.0117x + 0.1658 R^2 = 0.9998
				Immigration rate: y = 0.0016x + 0.0146 R^2 = 0.9756
Area of Chongqing				Area = 82400 km^2
Industrial fixed investments (10^4 RMB) **	Primary industry			y = 236276ln(x) - 29374
	Secondary industry	Mining industry		y = 325434ln(x) - 116188
		Manufacturing industry	Food industry	y = 76904ln(x) + 129056
			textile industry	y = -19544ln(x) + 63494
			Paper industry	y = -8707ln(x) + 28425
			Chemical industry	$y = 458435x^{0.1642}$
			Pharmaceutical industry	78056.27
			Metal and non-metal products industry	y = 217902ln(x) + 536929
			Automobile manufacturing industry	$y = 549957x^{0.4289}$ R^2 = 0.9152
			Other manufacturing industry	y = -55973ln(x) + 527364
		Power sector		y = 323193ln(x) + 274375

	Tertiary industry	Construction industry	y = 87077ln(x) + 38357
		Transportation, posts and telecommunications, warehousing industry	y = 1E+06ln(x) + 886374
		Wholesale and retail distribution industries, accommodation and catering industry	y = 6E+06ln(x) + 189313
Energy consumption per capita***	Coal consumption per capita	y = -0.0025x + 0.0655	
	Oil consumption per capita	1.79E-03 $\times 10^4$t/10^4 population	
	Nature gas consumption per capita	y = 7E-05x + 0.0017	
Carbon sink****	Urban forest coverage rate	y = 0.0535ln(x) + 0.2816	

Note: * Birth rate and mortality rate are calculated as an average among 1997 to 2007; ** x is the time of year, y is the fixed investment value of the year; *** x is the time of year, y is the energy consumption per capita; **** Urban forest coverage rate is calculated by the statistical data of 2005-2007

4. Low carbon scenario analysis for Chongqing city

This section presents three scenarios for Chongqing's energy consumption and related CO_2 emissions up to 2020. It explains the crucial technologies for Chongqing city as it leaves a business-as-usual trajectory and embarks on a low carbon pathway. This is followed by a bottom-up analysis identifying specific low carbon technology investments in key sectors.

The scenarios demonstrate the technical feasibility and investment affordability of a shift to a low carbon economy in Chongqing. However, scenario analysis is not a prediction of the future; it is a valuable tool for exploring the impact of particular sets of policies on energy and emissions. Furthermore, these scenarios are based on a top-down methodology, which cannot fully capture the local situation for specific investment options identified from a bottom-up approach.

4.1. Defining the scenarios

By adjusting assumptions about the development and deployment of these technologies in the future, three scenarios were developed:

4.2. Case I – basic development scenario

This is based on the current economic development pattern. It includes current policy commitments to energy intensity and other key areas but assumes that no further policies are introduced.

4.3. Case II – macro-policy control development scenario

The main statistical parameters are shown in Table 3.

Table 3 Industry parameter setting of macro-policy control development scenario

Sector	Parameters	
Chemical industry	Energy consumption per GDP	y = -1E-05ln(x) + 1E-04

	of coal (10^4t/10^4 yuan)	
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -1E-07ln(x) + 2E-06
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -1E-06ln(x) + 1E-05
Metal and non-metal products industry	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -2E-05ln(x) + 2E-04
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -3E-07ln(x) + 4E-06
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -2E-07ln(x) + 2E-06
Power sector	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -4E-05ln(x) + 4E-04
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -8E-08ln(x) + 1E-06
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -1E-09ln(x) + 1E-08
Construction industry	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -4E-06ln(x) + 5E-05
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -2E-06ln(x) + 3E-05
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -1E-08ln(x) + 1E-07

Note: x is the time of year, y is the energy consumption per GDP; in this scenario, considering "Eleventh Five-Year Plan" put forward the goal is the unit GDP energy consumption by 20%, total energy consumption per GDP fell 14.38% during 2005-2008 and 2.2% in 2009.

4.4. Case III – low carbon development scenario

All the above policy scenario measures are included. Further efforts like the faster penetration of renewables and nuclear power are made to decarbonize the energy system. In particular, the low carbon scenario includes some optimistic assumptions about the rate of introduction of carbon capture and storage (CCS).

The main statistical parameters are shown in Table 4.

Table 4 Industry parameter setting of low carbon development scenario

Sector	Parameters	
Chemical industry	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -2E-05ln(x) + 2E-04
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -2E-07ln(x) + 2E-06
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -2E-06ln(x) + 2E-05
Metal and non-metal products industry	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -3E-05ln(x) + 2E-04
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -5E-07ln(x) + 4E-06
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -3E-07ln(x) + 2E-06
Power sector	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -5E-05ln(x) + 5E-04
	Energy consumption per GDP	y = -1E-07ln(x) + 1E-06

	of oil (10^4t/10^4 yuan)	
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -2E-09ln(x) + 1E-08
Construction industry	Energy consumption per GDP of coal (10^4t/10^4 yuan)	y = -7E-06ln(x) + 6E-05
	Energy consumption per GDP of oil (10^4t/10^4 yuan)	y = -3E-06ln(x) + 3E-05
	Energy consumption per GDP of natural gas (10^8m^3/10^4 yuan)	y = -2E-08ln(x) + 2E-07

Note: x is the time of year, y is the energy consumption per GDP; in this scenario, total energy consumption per GDP increases 66.7% to reach the world average in 2006. (Source:[9])

5. Results

The model ran with a time-step of one stage spanning three scenarios with scenario 1 being the base scenario, and scenario 2 and 3 as the target stage. The coefficients of each parameter (e.g. sharing coefficients of irrigation and of industry) in the model were set according to results of previous studies.

5.1. Case I – basic development scenario

The results of the models are presented in Figure 3 and 4. Emissions under the base development scenario continue to grow at a rapid rate until 2020, showing little sign of tailing off. This would imply considerable stress on the energy supply and a growing exposure to fossil fuel prices.

Under each scenario, Chongqing's energy consumption will continue to increase until 2020. This will ensure its development and will create space for heavy industry to grow more efficient in the medium term while economic restructuring takes place. It is important to recognize the fact because heavy industry is a major employer in Chongqing.

Under the basic development scenario, primary energy demand will increase from 15.62 million tons sce in 2007 to 31.26 million tons in 2010 and 39.34 million tons in 2020. Coal will still be the main energy source, accounting for 59% of all energy in 2020.

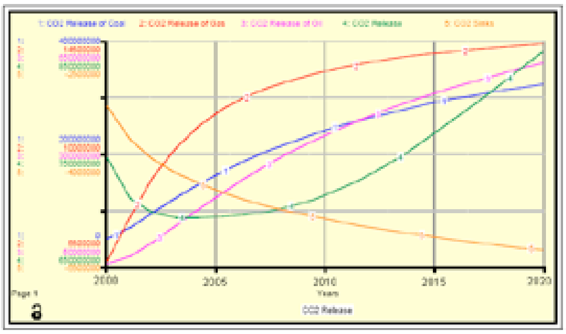


Fig.3 CO_2 emission associated with different energy forms in Case I

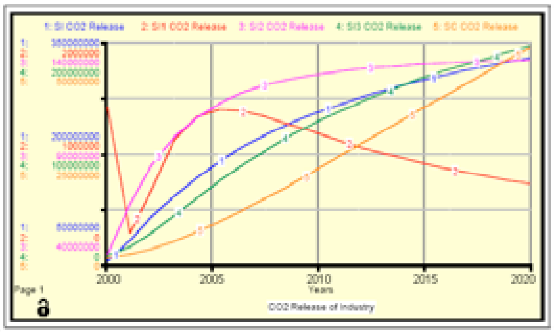


Fig. 4 CO_2 emission in different industries in Case I

5.2. Case II – macro-policy control development scenario

The energy-saving measures in the policy scenario help to reduce emissions compared to basic development scenario, and emissions had started to plateau by 2010. The additional supply-side measures in the low carbon scenario mean that after 2010, a significant additional emissions saving is achieved. This scenario includes an optimistic assumption about CCS; the potential for this is also represented in Figure 5 and 6.

A major finding from the scenario analysis is that low carbon and energy-saving policies can dramatically improve Chongqing's position – to such a degree that emissions for Chongqing could peak around 2010 and will have declined to 60% of the business-as-usual scenario by 2020.

Because of various energy-related measures in the policy scenario, primary energy demand falls to 28.18 million and 33.51 million tons sce in 2010 and 2020 respectively. Coal will account for 55.5% and 53.7% respectively of primary energy. The share of nuclear power will be up to 5% and 8% respectively and that of wind power will be up to 2% and 3% respectively.

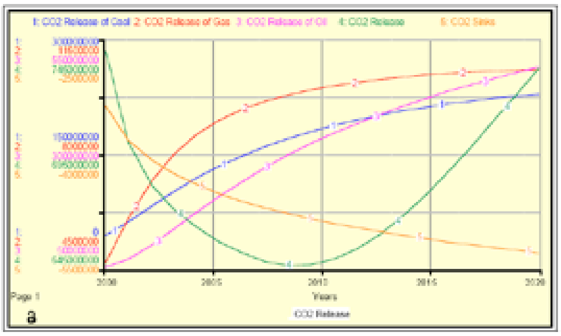


Fig.5 CO_2 emission associated with different energy forms in Case II

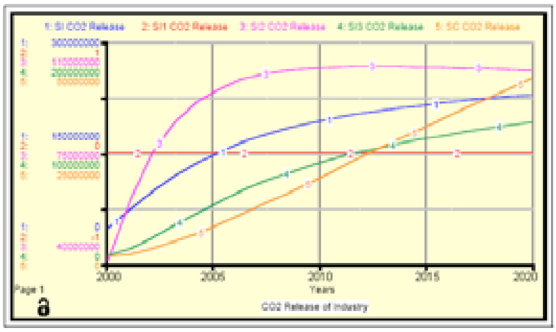


Fig. 6 CO_2 emission in different industries in Case II

5.3. Case III – low carbon development scenario

Under the low carbon scenario, Chongqing sets low carbon economic development strategy as a key goal in social and economic development – perhaps within a low carbon development area or zone. The overall energy saving is the same as what has been stated in the policy scenario, but additional CO_2 reduction measures are achieved by further decarbonizing the energy supply. In particular, the model assumes significant penetrations of CCS.

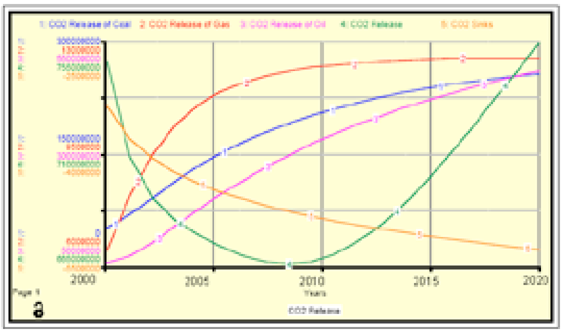


Fig.7 CO_2 emission associated with different energy forms in Case III

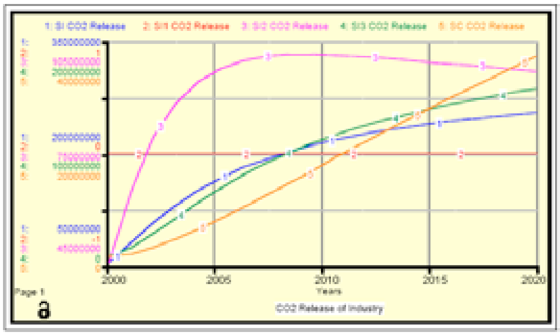


Fig. 8 CO_2 emission in different industries in Case III

6. Policy proposals of low-carbon restructuring for energy sector in Chongqing

The reduction in the greenhouse gas emissions in Chongqing energy industry shows that, in terms of the improvement of power generation efficiency, the overall net coal consumption rate in Chongqing is higher than the average level in China. According to the results of the scenario analysis, by eliminating the backward production capacity and constructing new highly effective thermal power generating units and gas generator sets, the energy efficiency of power plant is highly likely to reach the international advanced level in 2020. From the perspective of improving the power generation structure, nuclear power is the biggest factor contributing to the improvement of the future power generation in Chongqing, followed by the natural gas power, hydropower, biomass power and wind power.

The major tasks for the low-carbon economy transformation in Chongqing's energy industry are as follows: (a) optimizing the energy structure and increase the proportion of clean energy, (b) increasing the energy efficiency of the coal mining and washing and enhance the comprehensive utilization of the coal-bed methane (c) improving the energy conversion of the power plant (d) actively constructing the CCS model project and strongly promoting the development of carbon trade market and (e) strengthening the enterprises' management level of the energy industry.

In response to the tasks above, the research proposes several suggestions for policy making: (a) issuing the special project for Chongqing's energy development and new energy development as soon as possible, (b) perfecting the clean energy price developing mechanism and providing multi-channel financing platform, (c) overall planning the power generation and increasing the threshold of the newly built power plants, (d) promoting the technological reforms in energy industry and establishing the exit mechanism for backward production capacity, (e) enhancing talents cultivation and introduction and setting up and perfecting a connected system of Industry-University-Research.

7. Conclusion

China will need a variety of low carbon cities and regions to innovate and lead the way in policy-making. This dynamic low-carbon model would benefit from the allocation of decision-making powers in the areas of regulation, policy-making and planning for low carbon development so that Chongqing and other regions would have the opportunity to experiment with new approaches. Independent evaluation of policy success has also been identified as an important dimension. Policy implementation and monitoring should be led by an independent policy evaluation organization, ensuring the objectivity and impartiality of the evaluation result.

8. Acknowledgement

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