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Comprehensive Analysis of the Environmental Benefits of Introducing Technology Innovation in the Energy Sector: Case Study in Chongqing City, China

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Abstract

Because of the serious damage caused by acid rain, Chongqing city was designated as an Acid Rain Control Zone by the Chinese Central Government. The main factor responsible for the acid rain is the ever-increasing emission of sulfur dioxide (SO_2) due to utilization of coal as the primary energy source to meet increasing energy demand. Simultaneously, CO_2 emission has dramatically increased with coal utilization. In order to transform the current energy structure, alternative renewable energy technologies must be identified and proved feasible and effective. This research aims to comprehensively analyze the benefits of small-scale hydropower and wind power technologies to reduce SO_2 and Greenhouse gases (GHG). For this purpose, we constructed a dynamic comprehensive evaluation model based on an Input-Output (I/O) analysis for the period 2010-2020. The simulation results indicate that the introduction of small scale hydropower and wind power technologies have a positive impact on Chongqing's socio-economic, environmental and energy development in the first half of the study period. However, the results also show that the scarcity of renewable energy technologies to meet the increasing energy demand as well as the stricter emission constrains affect both economic growth and SO_2 and GHG reduction efforts from the latter half of the study period. To address this weakness, the study suggests that additional advanced renewable energy technologies are necessary as well as specific regulations to meet air pollution reduction targets. Last but not least, some feasible policies are proposed by analyzing the potential economic benefit of reducing air pollution and GHG emissions in terms of improved quality of life and environmental conservation. We argue that these benefits could offset the lower GRP growth obtained by the proposed policy.

Keywords: acid rain, greenhouse gas, dynamic input-output model, renewable energy technology, simulation analysis

1. Introduction

The access to a stable energy supply is a very important condition to achieve sustainable development. China has largely relied on the utilization of fossil fuels, especially coal, as a primary energy source to meet increasing demand for economic development. This situation has led to an inappropriate energy consumption structure. Furthermore, environmental degradation including acid rain associated with this unsustainable energy structure is becoming more prominent, with the rapid economic development. Renewable energy, an effective tool in reducing SO_2 and GHG emissions and in providing energy supply, has attracted increasing attention worldwide as clean energy resource (Dincer, 2000; Menegaki, 2008; Zheng, Zhang, Yu, & Lin, 2011). Chongqing is a typical area in this respect; almost all of its energy comes from fossil fuels particularly coal. The proportion of coal to the total energy utilization was 70 % in 2010 (Chongqing Municipal Bureau of Statistics, 2011). The reliance on coal for energy supply has caused environmental problems including acid rain and air pollution in addition to the rapid increase in GHG emissions. It is significant for Chongqing to introduce renewable energy technologies to improve the local energy structure while achieving the SO_2 and GHG emission targets set by the Chinese Central Government. Chongqing is located in Southwest China, where the distribution rate of economically exploitable hydro resources in China is 58.9 % (Huang & Yang, 2009). This means hydropower will be an important potential renewable energy contributing to energy structure transformation. Additionally in

the "12th Five Year Plan", the Chongqing government plans to introduce wind power technologies to promote the wind power industry. In this process, evaluation of candidate renewable technologies is a significant step for government policy-makers to decide budget allocation, mitigation plans, energy and economic development. Consequently, the specific objectives of this study are to comprehensively analyze the impact of small-scale hydropower and wind power technologies to explore renewable energy potential in Chongqing and the feasibility of introducing these technologies. We chose the "Chongqing Siyangping 49.3 MW Wind Power Project" and the "9.6 MW Xiaohe Small Hydropower Project, China", registered CDM projects as reference for the potential of renewable energy introduction. "Renewable technologies" refers to these two kinds of technology projects in this paper.

Recently, many studies employing Input-Output models have been undertaken to comprehensively evaluate policies which act as a motivation to make optimal balance between economic development and environmental protection. Mizunoya and Higano (1999) simulated an optimal tax-subsidy to reduce air pollutant (CO_2, SO_2, NO_x) emissions in Japan. Li et al. (2012) analyzed the impact of a recycling tax on metal recycling and GHG emission. Sakurai et al. (2003) proposed an environmental tax rate to maximize GDP under restriction of GHG emission based on an I/O model. Li and Higano (2004) simulated the best environmental tax rate for policies to introduce renewable energies for emission reduction in China. Wang et al. (2012) investigated an environmental tax to develop biomass power technologies for GHG mitigation.

However, limited research has been undertaken to comprehensively evaluate the benefits of renewable energy technologies via a simulation model and later identify the feasibility of introducing them. In this study, we propose an integrated environmental management policy using a computer simulation that includes the introduction of renewable energy technologies to improve the air quality in Chongqing and minimize GHG emissions while achieving optimal economic development. Three sub-models (material flow balance model, socio-economic model and energy balance model) and one objective function, gross regional product (GRP), were included in the simulation. The paper also describes the methodology of the Input-Output model and puts forwards a comprehensively initial policy analysis.

2. Method

This paper focused on building a comprehensive simulation model system to forecast environmental improvement potential based on input-output table and balances simulating social, economic and environmental developments. The simulation model considered significant factors, such as GRP growth, energy consumption and the existing individual sub-sectorial policy targets.

This study utilized an optimization simulation model, comprising dynamic linear LINGO programming, to evaluate the impact of the renewable energy technologies on gas emission reduction along with optimized economic development in the research area. The comprehensive simulation model can precisely estimate the benefits that may result from social, economic, and environment policy decisions.

2.1 Scheme of the Simulation Model

The simulation model is composed of 3 sub-models (socio-economic model, air emission model and energy demand-supply model) and one objective function (Figure 1). Chongqing's social and economic activities provide the simulation base and reflect real social and economic development. Three economic agents (industry, household, government) were assumed in this research. Figure 2 shows the commodity, SO_2 and GHG flow between economic agents. Based on the relationship between economic agents, we design the comprehensive evaluation model.

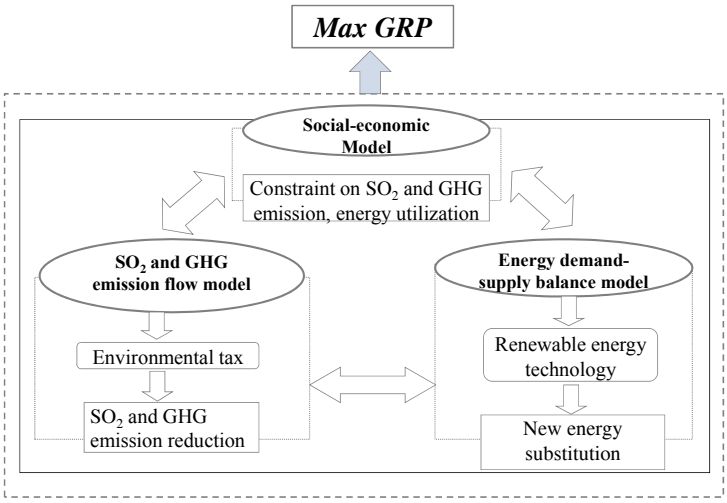

Figure 1. Model framework

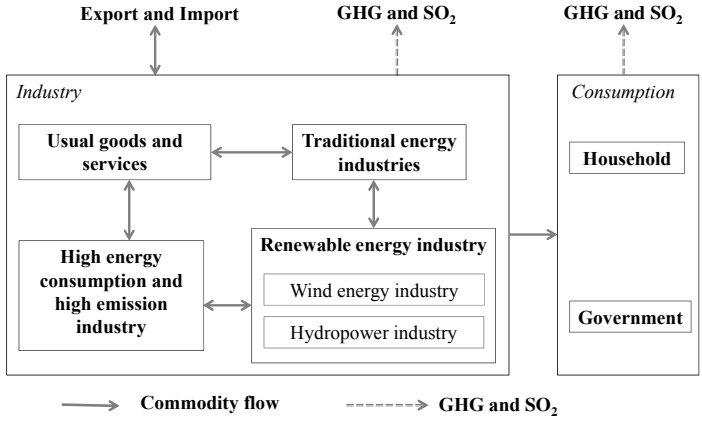

Figure 2. Relationship between agents in the social-economic and environmental model

As shown in Table 1, there are four big industries in the model. Each industry contains several sectors. We calculated the input coefficients between economic agents based on "2010 Input-Output table of Chongqing".

Table 1. Classification of industries in the model

Industry	Sector	Sector
1. Usual goods and services	Agriculture, Forestry, Animal Husbandry & Fishery	Waste treatment
	Transport and Postal Services	Other Industries
2. Traditional energy industries	Production and Supply of Electric Power	Production and Supply of Gas
3. High energy consumption and high air emission industries	Mining and Washing of Coal	Manufacture of Non-metallic Mineral Products
	Manufacture of Raw Chemical Materials and Products	Smelting and Pressing of Ferrous Metals
4. Renewable energy industries	Wind Power Energy	Small-Scale Hydropower

2.2 Design of the Simulation Model

In the simulation model, the variables are divided into endogenous (*en*) and exogenous (*ex*). The exogenous parameters are calculated based on current data; the endogenous variables will be determined by the model structure. The research period is 11 years, from 2010 to 2020. The selection of the research period was based on the availability of specific government targets for both SO_2 and GHG emissions. The objective function of this simulation is to maximize GRP of the study area and it can be formulated as:

$$Max\sum_{t=1}^{11}\left(\frac{1}{1+\rho}\right)^{t-1} GRP(t) \quad (\rho = 0.05) \tag{1}$$

$$GRP(t) = V_1X_1(t) + V_2X_2(t) + V_3X_3(t) + V_4X_4(t) \tag{2}$$

Where, *GRP (t)* is the gross regional product in term *t (en)*, $X_i(t)$ is the production of each industry *i* in term *t (en)* and ρ is the social discount rate. V_i is the value-added rate of industry *i (ex)*. The objective function is subject to the following constraints.

2.2.1 Balance of the Material Flows

In Formula 3, the left side represents the supply and the right side represents the demand. Usually, the supply is not lower than the demand. The input coefficient of production is calculated based on the 2010 input-output table of Chongqing.

$$X(t) \geq \sum_{j=1}^{4} A_{ij}X_j(t) + C_i^h(t) + \overline{C}_i^g + I_i(t) + \overline{E}_i - M_i(t) \quad (i = 1...4) \tag{3}$$

$X_i(t)$: commodity of each sector in industry *i* (*en*, column vector)

A_{ij}: input coefficients from industry *i* to industry *j* (*ex*, matrices)

$C_i^h(t)$: household consumption of each sector in industry *i* (*en*, column vector)

$\overline{C}_i^g$: government consumption in each sector in industry *i* (*ex*, column vector)

I_i: investment in each sector in industry *i* (*en*, column vector)

$\overline{E}_i(t)$: export of each sector in industry *i* (*ex*, column vector)

$M_i(t)$: import of commodity of each sector in industry *i* (*en*, column vector)

2.2.2 Energy Flow Balance

The energy supply in left side is not lower than the energy demand from industries, household consumption, export and import.

$$X_e(t) \geq \sum_{i=1}^{4} A_{ei}X_i(t) + C_e^h(t) + \overline{E}_e - M_e(t) \tag{4}$$

Where $X_e(t)$ is energy supply and A_{ei} is input coefficient

2.2.3 Value Balance

The left side of the formula is the income and the right side includes expenses. The income of each industry is equal to the expenses.

$$P_i(t)\tilde{X}_i(t) = P_1(t)A_{1i}\tilde{X}_i(t) + P_e(t)A_{ei}\tilde{X}_i(t) + P_3(t)A_{3i}\tilde{X}_i(t) + Y_i^h(t) + \delta_i\tilde{X}_i(t) + \tau_i\tilde{X}_i(t) \tag{5}$$

$P_i(t)$: price rates of each sector in industry *i* (*en*, row vector)

$Y_i^h(t)$: national income of each sector in industry *i* (*en*, row vector)

δ_i: depreciation rate of each sector in industry *i* (*ex*, row vector)

τ_i: indirect tax rate of each sector in industry *i* (*ex*, row vector)

2.2.4 Air Emission Balance

Gases are emitted by industrial activities, household and government consumption.

$$TP^{SO_2}(t) = \sum_{i=1}^{4} IE_i^{SO_2}X_i(t) + CE^{SO_2}(l^tC^n(t) + l^tC^g(t)) \quad (i = 1...4) \tag{6}$$

$TP^{SO2}(t)$: total amount of SO_2 emission (*en*, scalar)

IE_1^{SO2}: SO_2 emission coefficient of industry 1 (*ex*, row vector)

IE_2^{SO2}: SO_2 emission coefficient of industry 2 (*ex*, row vector)

IE_3^{SO2}: SO_2 emission coefficient of industry 3 (ex, row vector)

IE_4^{SO2}: SO_2 emission coefficient of renewable energy industry (*ex*, row vector)

CE^{SO2} : consumption subject SO_2 emission coefficient (*ex*, scalar)

$$W^{CO_2}(t) = \sum_{i=1}^{4} IE_i^{CO_2} X_i(t) + CE^{CO_2}(l^t C^n(t) + l^t C^g(t)) \tag{7}$$

$$W^{CH_4}(t) = \sum_{i=1}^{4} IE_i^{CH_4} X_i(t) \tag{8}$$

$$W^{N_2O}(t) = \sum_{i=1}^{4} IE_i^{N_2O} X_i(t) \qquad (i = 1...4) \tag{9}$$

$$W_{GHG}(t) = W^{CO_2}(t) + 21W^{CH_4}(t) + 310W^{N_2O}(t) \tag{10}$$

$IE_i^{CO_2}$: CO_2 emission coefficient of industry *i* (*ex*, row vector)

$IE_i^{CH_4}$: CH_4 emission coefficient of industry *i* (*ex*, row vector)

$IE_i^{N_2O}$: N_2O emission coefficient of industry *i* (*ex*, row vector)

$IE_4^{SO_2}$: SO_2 emission coefficient of renewable energy industry *i* (*ex*, row vector)

CE^{CO_2} : CO_2 emission coefficient of consumption subject (*ex*, scalar)

$W^{CO_2}(t)$: total amount of CO_2 emission (*en*, scalar)

$W^{CH_4}(t)$: total amount of CH_4 emission (*en*, scalar)

$W^{N_2O}(t)$: total amount of N_2O emission (*en*, scalar)

$W^{GHG}(t)$: total amount of GHG emission (*en*, scalar)

2.2.5 Constraints on the Amount of SO_2 and GHG Emission

$$TAG(t) \le b$$

b: the upper bound emission (*ex*, column vector)

2.2.6 Government Income and Expenses

In the formula 12, the right side represents the government revenue. It consists of direct taxes and indirect taxes. The government expenses include consumption, saving and capital depreciation.

$$T^g(t) = \tau^d \sum_{i=1}^{4} l^t Y_i^h(t) + \sum_{i=1}^{4} \tau_i X_i(t) \tag{12}$$

$$T^g(t) = l^t \bar{C}_1^g + S^g(t) + \delta_g K_g(t) \tag{13}$$

τ^d : direct tax rate (*ex*, scalar)

$T^g(t)$: total government income (*en*, scalar)

$S_g(t)$: total government saving (*en*, scalar)

2.2.7 Household Disposal Income, Consumption and Saving

$$Y_d^h(t) = (1 - \tau^d) \sum_{i=1}^{4} l^t Y_i^h(t) \tag{14}$$

$$P_1(t)\tilde{C}_1^h(t) = Y_d^h(t)\alpha_1 \tag{15}$$

$$P_e(t)\tilde{C}_e^h(t) = Y_d^h(t)\alpha_e \tag{16}$$

$$P_3(t)\tilde{C}_3^h(t) = Y_d^h(t)\alpha_3 \tag{17}$$

$$S^h(t) = \beta Y_d^h(t) \tag{18}$$

$$l^t\alpha_1 + l^t\alpha_e + l^t\alpha_3 + \beta = 1 \tag{19}$$

Y_d^h: household disposable income (*en*, scalar)

α_1: usual industry consumption rate (*ex*, row vector)

α_e: energy industry consumption rate (*ex*, row vector)

α_3: high energy consumption and high air emission industry consumption rate (*ex*, row vector)

β: saving rate (*ex*, scalar)

2.3 Case Setting

In this paper we adopted SO_2 and GHG (Table 2) as the environment control index in simulation and used it in the case setting. We proposed four different cases ranging from business as usual (BAU) to emission constrains and the introduction of renewable technologies as shown in Table 3.

We set Case 0-∞ as the BAU scenario without renewable technology introduction and gas emission constraints; that is, the case based on forecasting and analyzing the economic trends in Chongqing during the period 2010-2020. Specifically, in order to demonstrate the contribution of renewable technologies to local development, emission restrictions compared with the base year are proposed in the alternative models as shown in Case 0-200 %, Case 1-200 % and Case 1-150 %. For instance, Case 0-200 % means the amount of gas emission each year is not larger than twice the amount emitted in 2010. In case setting, we selected 2 and 1.5 times the emission amount in 2010 as the emission upper boundary. We did this selection based on the fact that lower emission constraints would result in extremely low GRP growth.

In this paper air emissions are divided into air pollutant gas and GHG.

Table 2. Types of air pollutants

Index	Air pollutant	Index	GHG
1	SO_2	1	CO_2
		2	N_2O
		3	CH_4

Table 3. Case setting

Case	Scenarios	Gas constraint	Renewable technologies
BAU	Case 0-∞	No	No
Case 0	Case 0-200 %	<=200 %	No
Case 1	Case 1-200 %	<=200 %	Yes
	Case 1-150 %	<=150 %	Yes

In case setting, “Yes” does not necessarily mean that the renewable technology is adopted. After the technology assessment through the simulation, if the technology has advantage, it will be adopted.

3. Results and Discussion

Four scenarios are established to evaluate the environmental and economic benefits of introducing renewable energy technologies. The simulation provides an effective approach to estimate gas emission, economic and energy utilization trends through the comprehensive system. Compared with the actual social-economic and environment development, the simulation system is proved as an effective tool in technologies and policies assessment.

3.1 Air Emission Trends

The simulation results indicate that along with high economic growth rate (17.7 % in 2010), the air pollution and GHG emissions will inevitably increase. As shown in Figure 3, the CO_2-e amount and emission trends are increasing with a high growth rate in BAU scenario and reach 1.42 billion tons in 2020, which is more than 7 times the amount in 2010. To put in perspective, the total CO_2-e emission amount in Chongqing city under BAU conditions will be more than the current GHG emissions in Japan that reached 1.261 billion tons in 2011. In addition, SO_2 emissions also increase with a high growth rate reaching 5,073,510 tons in 2020 in the BAU scenario (see Figure 4). However, in the alternative scenarios the emission trends keep a low growth rate with the emission constraints as shown in Figure 3 and 4. By comparing the emission amount of BAU and case 1-200 % the total reduction could reach 5.64 Billion Ton CO_2-e and 16,323,223 Ton SO_2 in the research period

(2010-2020). To have a clearer idea about the amount of emission savings we can state that these emissions are equivalent to 55 % of the total CO_2-e emissions and 59 % of the total SO_2 emissions in China in 2010 (Zhao, Zhang, & Nielsen, 2012).

Many factors that contribute to the emission trends were shown in Figure 3 and 4. Firstly, from model perspective, we maximize total products added-value in each industry (Equation (1) and (2)) in the study period as the objective function and the gas emissions amount are decided (Equation (6)-(11)) by the emission intensity and product in each industry. The gas emission intensity of each industry is constant and calculated based on *IPCC Guidelines for National Greenhouse Gas Inventories* (2006) (Eggleston, Buendia, & Miwa, 2006) and Chongqing energy consumption statistic in Yearbook 2011. Therefore, the gas emission amount is mainly decided by the product value in each industry if there is no emission constraint (Figure 3, 4 and 6: BAU emission trend). On the contrary, the gas emission constraints will have an impact on economic development (see Figure 8). Secondly, the energy technology introduction in this research pushes the renewable energy industry development which not only contributes to both SO_2 and GHG emission reduction (Figure 3 and 4) but also to moderate economic development (Figure 8 and 9).

Simultaneously, introducing technology innovation in the energy sector creates multiple benefits. Firstly, although many researches have been undertaken to measure the economic cost of climate change and air pollution (Haines et al., 2007; Matus et al., 2012), some benefits and costs do not have monetary values, such as quality of life, extended life span, good health, etc. From an environmental and health perspective, the CO_2-e emission reduction potential of 5.64 Billion Ton (see Figure 3) in the research period (2010-2020), compared with BAU and case 1-200%, contribute a lot to climate change mitigation. Climate change may be considered as a key factor for environmental change, exposure to health risks and pathogens (Pascal, Viso, Medina, Delmas, & Beaudeau, 2012). China's rapid development has come at the cost of severe environmental degradation: outdoor air pollution is associated with more than 300,000 deaths, 20 million cases of respiratory illness, and a health cost of more than 500 Billion CNY (more than 3% of gross domestic product) annually (Millman, Tang, & Perera, 2008). Chongqing air quality is worse than China's average level; the health loss would be much more serious than whole country average level (Andrew, 2012).

In addition, the introduction of renewable energy sources will not only reduce the emission of SO_2 but also other pollutants associated with fossil fuel consumption such as Hg, TSP, PM, etc. This will further contribute to improving quality of life and the environment.

Secondly, fossil fuels are non-renewable that will eventually become scarce and will become too expensive or too environmentally damaging to retrieve (Menegaki, 2008). Renewable energy utilization can increase fuel diversity and energy independence and could be an effective solution to mitigate the impacts of price fluctuation brought by economic or political instabilities.

Thirdly, from the economic development perspective, gas emission constrains and the introduction of renewable energy technology will push the high emission intensity sectors to adopt advanced technologies to improve production efficiency. In the long run, it promotes cleaner production - high value-added industries development and realize the development of the whole society. Figure 4 shows SO_2 mitigation potential 16,323,223 Ton contributed by gas emission constrains and energy technology introduction.

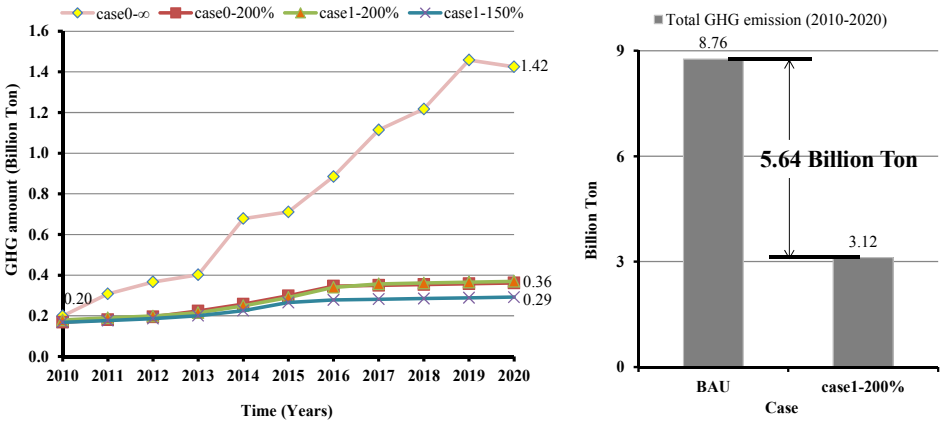

Figure 3. GHG Emission from 2010 to 2020

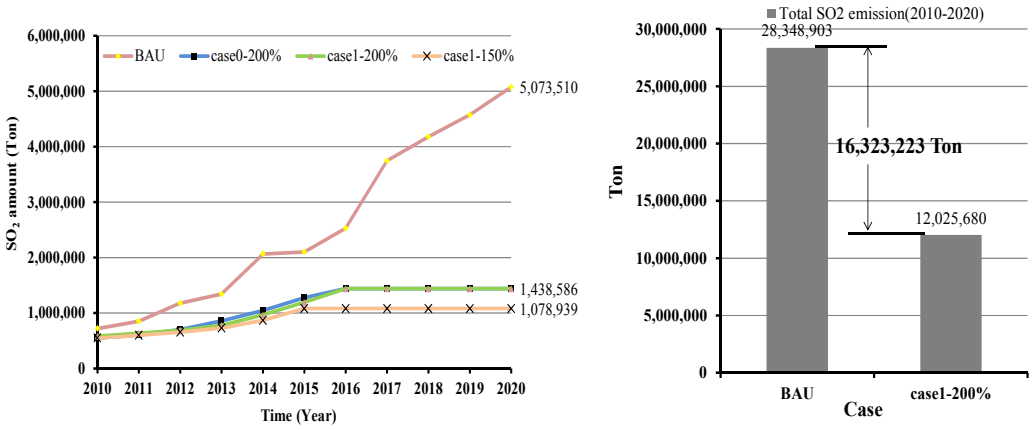

Figure 4. SO_2 emission from 2010 to 2020

3.2 Reduction Rate of GHG Emission Intensity and SO_2 Emission Amount

The Chinese government set the target to reduce the total amount of SO_2 emissions by 8 % in the year 2015 compared with 2010 (KPMG China, 2011). The Government also set the goal to improve the GHG intensity by 17 % in 2015 compared to 2010 and between 40-45 % by 2020 compared to 2005.

In this study, we take the GHG emission intensity and SO_2 emission amount reduction rate by 2015 clarified in the "12th Five-Year Plan" as specific short-term targets. Comparing the reduction rate by 2015 of the proposed scenarios with the target, we can identify the policy strengths and weaknesses in each scenario. This is an effective way to evaluate the policies and help improve them, which is the necessary process to achieve the 2020 climate objective which China committed to at the Copenhagen Conference in 2009.

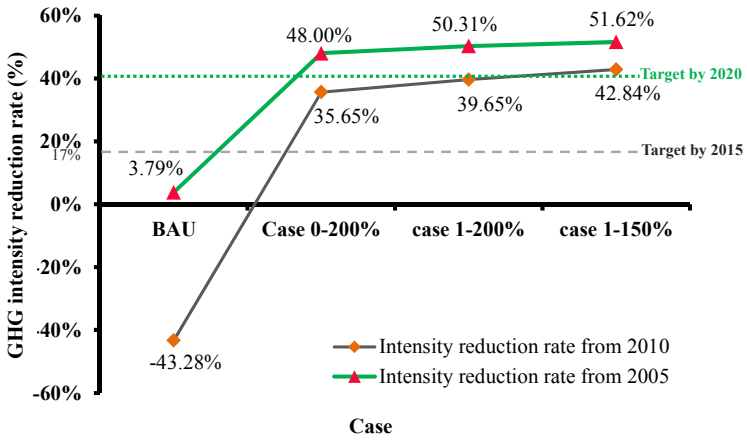

Figure 5. GHG emission intensity reduction and deviation from target in four scenarios

Figure 5 shows the GHG emission intensity reduction rate from 2010 and 2005 and their target by 2015 and 2020 in the four scenarios. Except for the BAU scenario, all proposed scenarios achieve the government target clarified in "12th Five Years Plan". In addition, the reduction rates in technologies introduction scenarios are much higher. This result suggests that the introduction of renewable technologies is necessary in pursuing sustainable development.

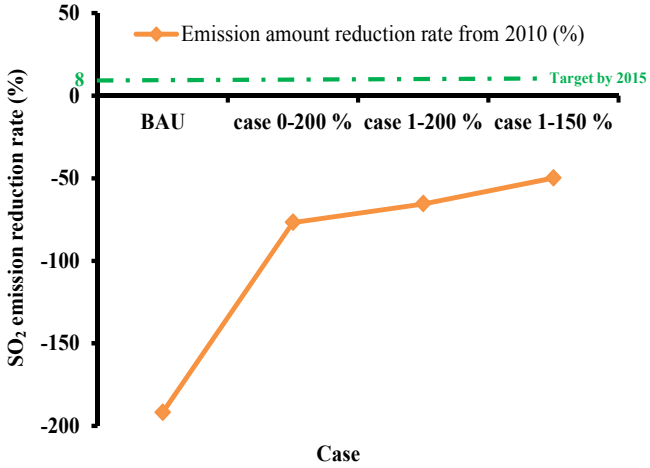

Figure 6. SO_2 emission reduction rate and deviation from target in four scenarios

Figure 6 shows the SO_2 emission rates reached by 2015 in the four scenarios and government target by 2015. Compared with government target (more than 8 % reduction) clarified in "12th Five Years Plan", the simulation result shows that no scenario will achieve the government target. However, the BAU scenario has a much wider gap with the government target; the total SO_2 emissions will almost triple compared with case 1-200 %. This poses an almost impossible challenge to overcome for Chongqing. While the other scenarios also show an increase in the SO_2 emissions, it would be much easier to improve the situation with the gas emissions constrain and technologies introduction. Based on the experience of other countries, it is possible to reduce the SO_2 emission amount significantly by the installation of SO_2 trapping technologies such as the flue-gas desulfurization devices (FGD) and introduction of monitoring regulation which guarantee that these devices operate efficiently based on Case 1-200 % or Case 1-150 % (Xu, Williams, & Socolow, 2009). The introduction of alternative renewable technologies (such as biomass technologies) as well as specific regulations to address air pollution (such as FGD for SO_2 and selective catalytic reduction for NO_2 in coal power plants) is expected to eliminate the gap gradually.

Case 1-200 % can be seen as the optimal proposed scenarios since the simulation result shows that its total GRP is the largest one under the same gas emission constraints, and the reduction cost is the lowest. Therefore we will analyze the economic-environmental benefit and energy conservation for Case 1-200 % to prove the feasibility of achieving the local government plan. In this case, gas emission control and the amount of renewable energy utilization can be used as guidelines in achieving optimal development.

The environmental and social benefits of introducing emission constraints and renewable technology will greatly benefit Chongqing in the long run offsetting the economic loss caused by lower GRP growth rate (see Figure 8). Compared with BAU, average GRP loss in case 1-200 % is 2.29 % annually (see Figure 7), which could be lower than the potential economic benefit associated with the reduction of 5.64 Billion Ton CO_2-e and 16,323,223 Ton SO_2. Dones et al. (2005) estimated the external cost of CO_2-e and SO_2 per ton in the Year 2000 in EU as 19 $€_{2000}$/ton CO_2-e and 2939 $€_{2000}$/ton SO_2. Based on their research we can calculate that the saving cost from both CO_2-e and SO_2 emission would be 1,223.96 Billion CNY. In the long run, if we include the impacts of other pollutants associated with coal power generation such as NO_x, Hg, PM2.5, etc; the external cost could be much higher in BAU scenario. In fact Andrew (2012) estimated that the annual cost of pollution amounts to 3% of the total GDP in China and the quality of life is a very important factor that must be taken into consideration.

3.3 Economic Development Trend

Under the SO_2 and GHG emission constraints, GRP in Chongqing showed steady improvement since 2010. It is clearly shown in Figure 7 that the total GRP amount is much higher in BAU than other cases. This means the introduction of SO_2 and GHG emission constraints will affect economic growth. However, as we mentioned in discussion before, the decrease in economic growth can be more than compensated with the benefits of much better quality of life in terms of human and environmental health at the local level as well as climate change mitigation at the global level.

Case 0-200 % and case 1-200 % are cases with the same SO_2 and emission constraints. The difference between them is that the latter has renewable technology introduction; there is a GRP increase from case 0-200 % to case

1-200 %; the contribution of renewable technologies to economic development is significant. The gap between them is 993 Billion CNY. From case 1-200 % to case 1-150 %, although the gas emissions are reduced, the total GRP amount and increase rate declined. The reason is that along with stricter limitations on gas emission, economic benefits are sacrificed for environment conservation. Although the renewable technology's contribution can achieve dual targets of economic development and environment protection (Figure 7: case 1-200 %), as it has stricter limits for gasses, it cannot be effective (Figure 7: case 1-150 %).

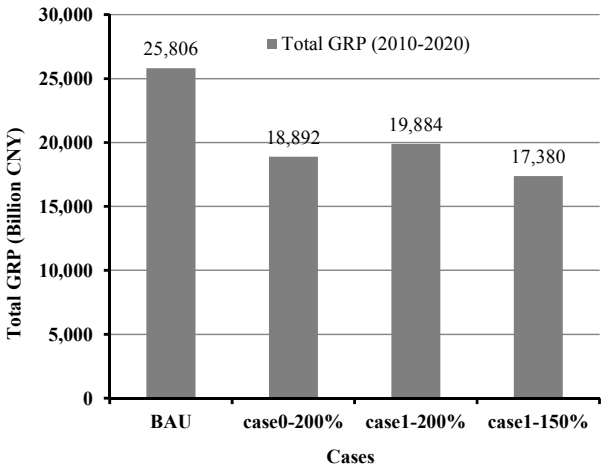

Figure 7. Total GRP amount with air emission reduction from 2010 to 2020

From the GRP trends (Figure 8) in case 0-200 %, case 1-200 % and case 1-150 %, we can see the overall rate of increase in the GRP is higher during the former half (2011-2015) than the latter half (2016-2020). There are 3 key drivers that contribute to that result. The first one is industries adjustment between high emission intensity sectors and low emission intensity ones; the second one is the introduction of renewable energy technologies and the third one is GHG, air pollutants emission constraints implemented through "12th Five Years Plan" of Chinese Central and local governments. The simulation result shows that in the first 5 years two scenarios (case 1-200 % and case 1-150%) achieved government GHG emission intensity reduction rate mitigation target clarified in "12th Five Years Plan" with a high economic development trend (see Figure 8) which is similar with BAU's. Simultaneously, while SO_2 emissions increase in the proposed scenarios, these increases are much lower than under BAU situation. In addition, they can also contribute to climate change mitigation caused by GHG emission, human health protection and air pollution reduction. The proposed policies in case 1-200 % and case 1-150 % are significant to realize both environmental and economic benefit in Chongqing.

In the first 5 years, the 3 key drivers mentioned above act as the different important roles to mitigate GHG and SO_2 emission (see Figure 3 and 4) and promote economic development with a high growth rate. The main benefit comes from the industry structure adjustment between high emission intensity sectors (such as: high energy consumption and high emission industries, traditional energy sector) and low emissions intensity departments (such as: manufacture of communication equipment, computers and other electronic equipment sector). In other words, the technology introduction will not only benefit by keeping economic growth with a high rate, but will also help reduce GHG and SO_2 emission compared to BAU as shown in Figure 3 and 4.

From the economic development trend in Figure 8, we can find the GRP gaps compared with BAU mainly happen in the period 2016-2020. This gap can be explained by two main reasons. First of all, GHG and SO_2 emission constrains affect economic development if there is no technologies innovation in any sector. Secondly, the potential small-scale hydropower and wind power capacity is limited. However, the policies contribute to GHG and SO_2 emissions reduction, which benefit to mitigate climate change and improve quality of life.

Therefore, from 2016, we need to consider other renewable energy sources such as biomass energy, and cleaner power generation technologies (IGCC) or cleaner fuels such as natural gas in addition to pollution control devices.

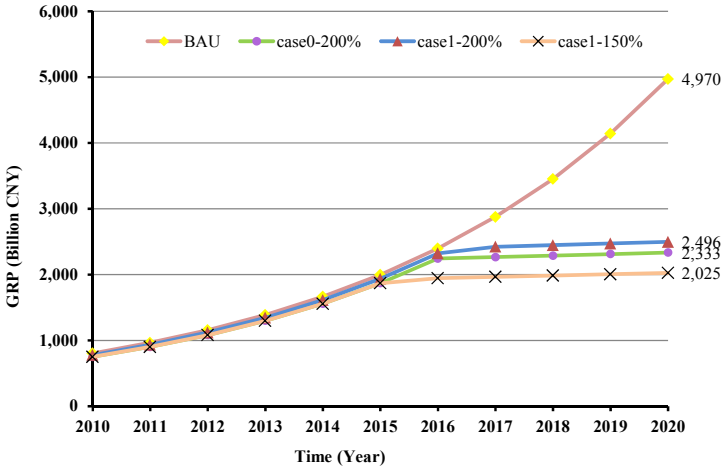

Figure 8. GRP trends with SO_2 and GHG reduction from 2010 to 2020

3.4 Renewable Energy Utilization Trend in Electricity Power Sector

We ran the simulation to find the renewable energy utilization potential from 2010 to 2020. With economic development and financial support in research areas, as shown in Figure 9 the total renewable energy usage amount is growing for the first 4 years. From 2014 the amount of renewable energy reached the upper boundary of local renewable energy capacity. The simulation results indicate that along with economic development, much more thermal power is necessary to support social economic development. That's why the rate of the constant renewable energy to total energy consumed decreases from 2013 to 2016. However, the thermal power industry which has a high gas emission coefficient cannot produce power according to demand as the gas emission constraints and industry structure adjustment acts as an effective tool to realize dual target from 2016 to 2020, which contribute to the rate of renewable energy power to total energy power increasing from 2016 to 2020.

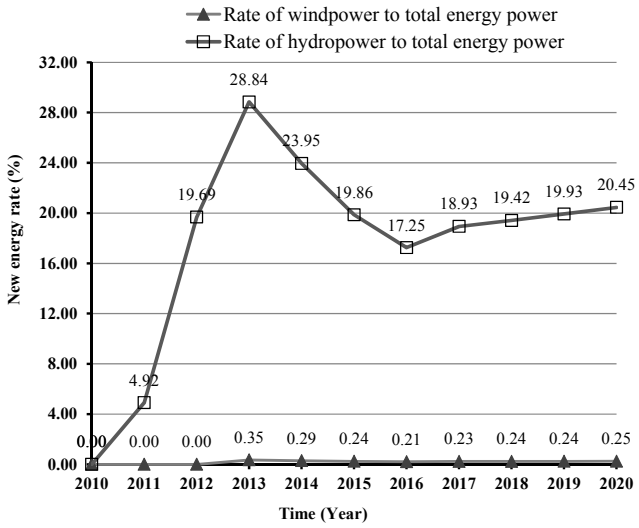

Figure 9. Trend of renewable energy utilization rate from 2010 to 2020

However, the absolute amount of renewable energy does not change from 2014. This simulation result shows that current technology will not be adequate to support a continued increase in energy demand in the latter years. This result calls for technological innovation to provide multiple scenarios for local development, such as the introduction of cleaner energy technologies to improve the efficiency of fossil fuel utilization.

4. Conclusion

In this paper, we used a comprehensive simulation model to find out the impact of introducing renewable technology to reduce GHG and SO_2 emissions and explore renewable energy resources. This study demonstrated that Chongqing can effectively address climate change and air pollution challenges by adopting an effective policy that combines emission restrictions and the introduction of renewable energy technologies. However, the environmental and health benefits were achieved at the expense of lower GRP growth.

From the scenario analysis, case 1-200 % provides benefits in terms of decreasing air pollution and increasing renewable energy utilization. The renewable energy can contribute to economic growth indicated by the simulation result. When the amount of gas emissions each year is not larger than twice of that in 2010, moderate economic development can be achieved; total GRP is 19,884 billion CNY, 993 billion Yuan more than case 0-200 % without renewable technology introduction. The simulation result found that the limitation of wind power and hydropower supply capacity will not be able to meet the energy demand in the study area affecting the economic growth of the region (less than 4 % growth) from the year 2017.

A rapid and effective solution to drastically reduce SO_2 emissions could be possible by introducing SO_2 trapping-technologies in the current coal power plants or by using clean coal. In the long term, renewable energy technologies introduction to explore renewable energy source could help achieve environmental objectives. This approach could not only benefit in terms of GHG and air pollutant mitigation, but also improve economic development and promote technological innovation. Emissions reduction will result in direct and immediate health benefits, especially for children. The benefits will accrue over their entire lifetime. Further research is necessary to analyze the economic benefit of improving the environmental and health quality in terms of reducing costs in health provision and improving the quality of life and determine if this benefit could balance the lower GRP obtained with the alternative scenarios.

This research has some limitations that call for follow-up research. Hydropower and wind power are not constant, which are affected by the climate and seasons. Electricity produced by them can be variable. Energy storage will be another urgent problem. Hydrogen and fuel cell technologies could offer solution to tackle the energy storage problem. Further studies will consider about introducing hydrogen and fuel cell technologies. In addition, we must also include NO_2 emissions that have increased very rapidly due to motorization.

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