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Research Article

A Simulation of Water Conservation Policy Impacts on Long-Range Climate Change: A CGE Analysis

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The study of “water-energy-carbon” has always been an important theme in natural science. With the concern of climate change, the relationship between water and carbon has also attracted attention. China has published several policies for the water conservation, and it has begun to explore the policy transform of the water fee into water tax, which will become a key economic measure for water management. In the background of the carbon reduction, the policy may influence both the water system and the carbon system. This study mainly analyzes how future water tax affects the climate change in China by using the macroeconomic model named the computable general equilibrium model (CGE model). Two scenarios with different tax ratios have been set, and policies are implemented among different sectors. The policy will not only directly impact these industrial sectors but also indirectly impact other sectors through the economic system, which will finally do tiny contribution to the long-term climate change. The working mechanism was discussed, and policy implications were proposed at last. Firstly, China should pay attention to the impacts of macropolicies on CO_2 reduction as it has set the goal of peaking carbon emissions and achieving carbon neutrality. Secondly, more study needs be carried out for the mechanisms of the “water-energy-carbon” process from the macroeconomic perspective for combing the climate change.

1. Introduction

Increasing countries have announced its carbon neutrality targets as realizing the acceleration of climate change. In China the action for CO_2 mitigation has been regarded as a profound reform which will impact its economics and society widely [1]. It is necessary to further study the water-energy-carbon (WEC) nexus for a better achievement of the targets and tackling climate change.

The process of the WEC nexus has been studied at the sector, regional, national, and global levels [2–7], which is a hot topic for both water conservation and coping with climate change. Research approaches such as the life cycle analyses, supply-chain analyses, input–output model, linkage analyses, and ecological network analyses have been employed widely in the field [4, 8–12]. In the side of water conservation, numerous studies address the impacts of climate change on the hydrological system such as its spatial heterogeneity. [13]. For example, Haro-Monteagudo et al. used a cascade modeling approach to study long-term sustainability of large water resource systems under climate change in Spain [14]. Masood and Takeuchi evaluated impacts of climate change and provided implications on future water resource management [15]. Wang et al. evaluated the water resource spatiotemporal pattern of the upstream Yangtze River corresponding to climate changes from 1999 to 2022 in China [16]. And actually, it is also needed to do research on the reverse process, as the water resource utilization can also affect CO_2 emissions and climate change. Lv et al. provided a review on water resource synergy management in response to climate change in China from the perspective of urban metabolism and pointed out that the water-energy-carbon nexus plays a significant role in alleviating the crisis of water and energy as well as in reducing CO_2 emissions [17]. Xu et al. analyzed the WEC metabolic system in China by using environmentally extended input-output and ecological network [18]. Wang et al. tried to find out the regional embodied WEC efficiency of China using the multiregional input-output approach [9]. Tian et al. studied the nexus of the intra- and interregional trade process in China [19] and Cai et al. analyzed the spatial–temporal nexus of WEC under the industrial transition [3]. In brief, the coupling of WEC represents the "Natural-Social-Economy" system, and most studies are from the "Physical energy cycle," "Ecological footprint," "Resource carrying capacity," or "Ecological services," etc. In the future, more research on this topic should be carried out in perspective of policy and economics.

Tax is regarded as a useful economic tool to manage natural resources and reduce CO_2 emissions, which is selected as the major objective of the article as there is little research on its impacts of the WEC process. The resource tax legislation was passed by the National People's Congress in 2019 [20], which indicates that the tax would replace water fees and become the key policy in China for water conservation in the following decades. In addition, high-water-consumed industries are always high-energy-consumed, which contributes large amount of GDP. Water tax will be likely implemented in those sectors firstly and will have synergy effects on the WEC process, affecting the climate change indirectly.

As a typical economic model, the computable general equilibrium (CGE) model has been successfully applied in the field of climate change and natural resource management etc. In terms of water conservation, it has been used for water prices [21], water resource allocation [22, 23], and water incentive policies [24]. Recently, there are also several studies on water resource tax policy, such as the impact of taxation on agricultural water consumption etc. [25]. Zhang uses the CGE model to simulate and calculate the optimal tax rate of China's water resources tax and puts forward reasonable suggestions [26]. A previous study has proved that the CGE model is feasible to do policy stimulation of water resource tax, and it can provide a good connection between the economics and the geophysics. But few studies focus on the tax policy impacting the WEC processes by using the CGE model in a long term.

The main purpose of this paper is to simulate the taxation policies implemented by using the CGE model, analyze the impacts of different tax rates on long-term range climate change, and find out the impacting mechanism to CO_2 emissions. Research paper is structured as follows: Section 1 mainly introduces the research background and literature. Section 2 introduces the research methodology and scenario assumptions. Section 3 discusses the results of modelling, and finally, policy implication was proposed.

2. The Relationship of the Water Resources, Energy, and Economy

The water consumption in industry sectors is mainly impacted by their technological level, enterprise scale, management level, and water efficiency. In the future, their water consumption will continuously grow, and there is a need to control the total amount through different types of measures, such as the advanced technology application and tax and subsidies. It needs to point out that most high water intensity sectors are high energy intensity sectors, and the water tax policy has a direct impact on the sector CO_2 and value-added, etc.

The water and carbon cycles are critical for human beings, and generally, research in the natural sciences focuses on the interaction between water-soil-energy-carbon, which is mainly in the form of water cycle, land use, energy cycle, and carbon cycle. This is the core element of the "nature-economy-society" system. In addition, the impacts of human society on the nature cannot be ignored, especially for the macropolicies, which can change the production efficiency and technological level, affecting the distribution of water and carbon. For the future "2030 carbon peak and 2060 carbon neutralization" goal, the synergy between the intensive use of water resources and energy needs to be addressed. There is a linkage of water conservation and carbon emission reduction, which can finally impact the climate change (Figure 1).

In fact, water resource tax is much popular than the administrative measures and has a certain basis in China. Firstly, the reform of natural resources has begun, and secondly, the market system has been initially formed. It can not only adjust the economy but also guide people to pay attention to water resource conservation and utilization. China has selected Hebei province as the water tax policy pilot since 2016, and it has implemented tax from the consumption process of both underground water and surface water, with a higher ratio in high-intensity water sectors.

3. Methods and Data

Water can impact both the economic system and the energy system directly (Figure 2). For the former one, sectors excepted for the high water intensity sectors are highly impacted too, and for the later one, water plays roles in the energy consumption process, such as the extraction, transportation, and fossil fuels. As we can prove, the water conservation measures can improve the energy efficiency, reduce energy consumption, and mitigate greenhouse gas emissions. The proposal of a WEC nexus plays a significant role in alleviating the crisis of water and energy as well as in reducing CO_2 emissions. Thus, we choose the integrated assessment model to simulate the impact of water resources tax, in which the economic model across sectors is quite important.

The CGE model is widely used to simulate the macroeconomic effects of public policies in both developed and developing countries. We use the basic model developed by Zhu et al. and Xue et al. [27, 28], which has been employed in the policy simulation of carbon tax [29] and VOC reduction, etc. [30]. The CGE model has gradually developed from static to dynamic, and the application on policy simulation has become much more accurate as we have made improvement combing the new parameters and modes, which is referenced from [31].

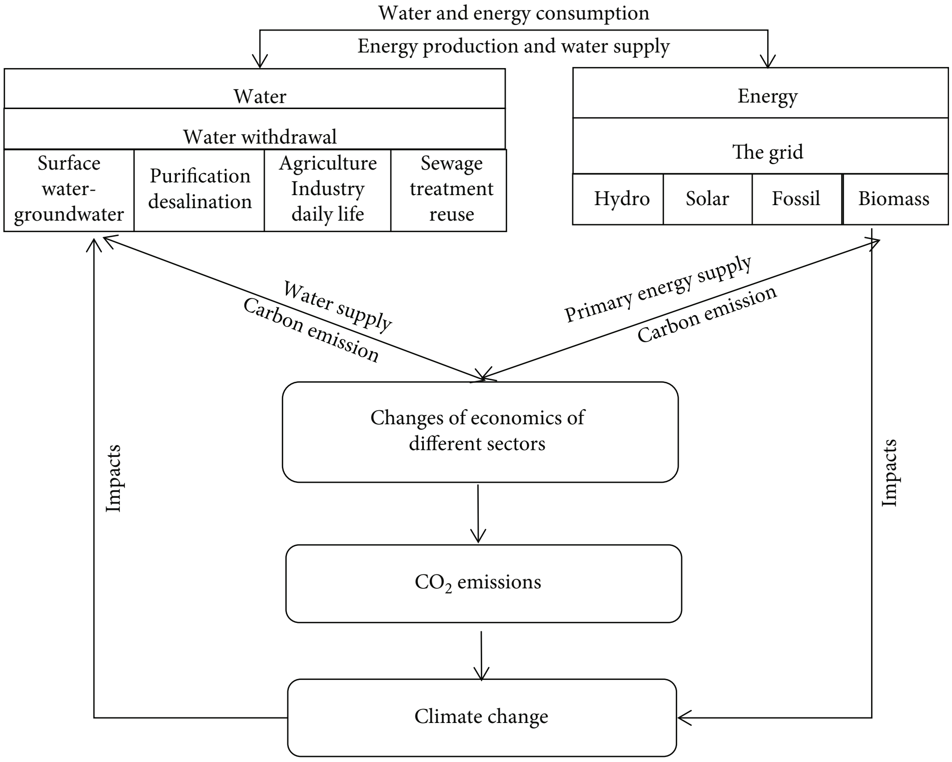

Figure 1: Water and energy cycle impacts climate change.

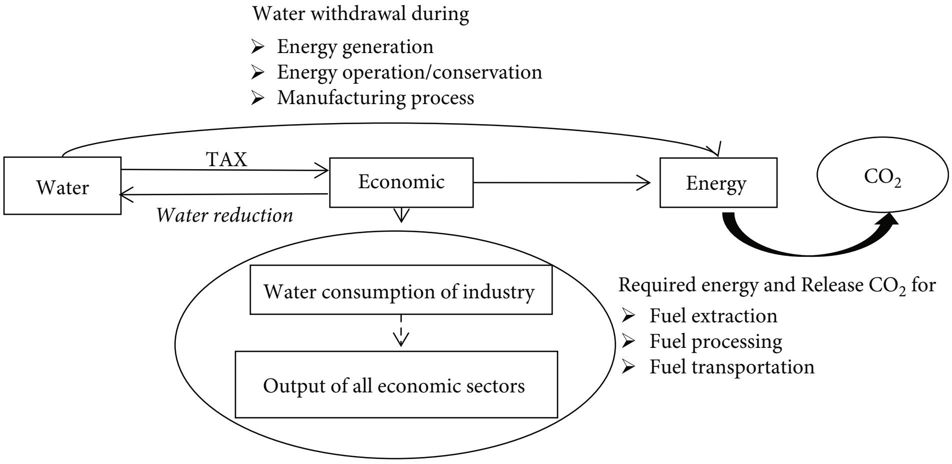

Figure 2: Tax policy impact the water and energy system.

3.1. Model Structure. The CGE model is based on the equilibrium modeling method with the social accounting matrix (SAM) to describe the general equilibrium relationship of the economic system.

The CGE model of this paper includes four modules, which are the domestic production module, the income and expenditure module, the foreign trade module, and the market module. Among them, the market module represents the balanced settlement relationship among economies in the whole market, including the balance of commodity supply and demand, the balance of activity cost and output, the balance of income and expenditure of the labor factor and capital factor, the balance of income and expenditure of residents, the balance of income and expenditure of the enterprise accounts, the balance of income of government accounts, the investment savings, balance of capital (the fixed asset investment and the increase of stock), and the balance of international payments, which are 10 equilibrium clearing relationships. The structure of the CGE model is shown in Figure 3.

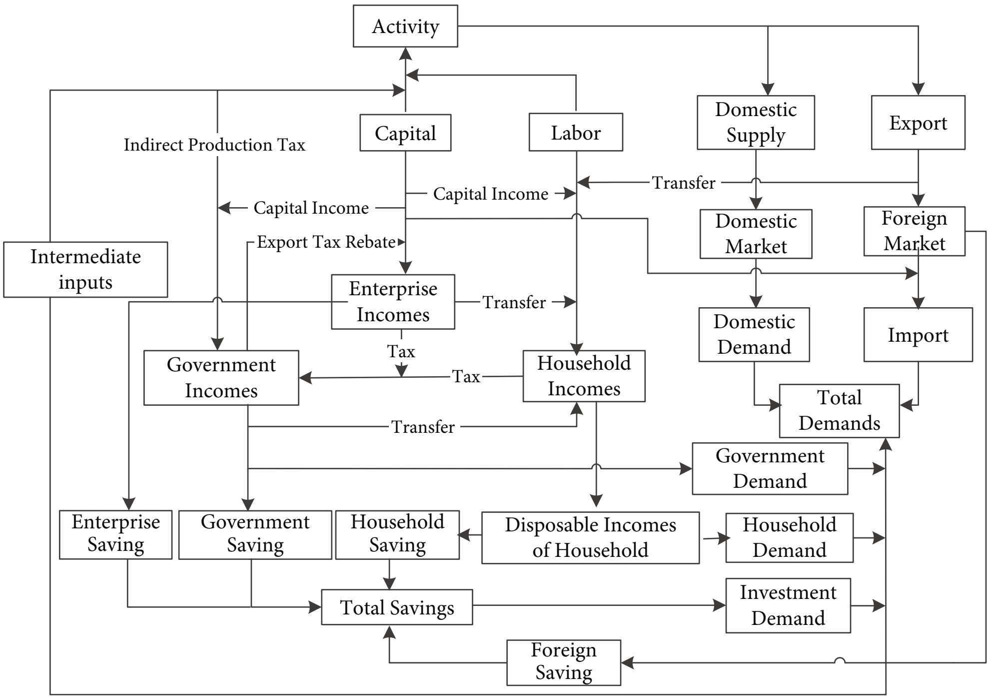

Figure 3: Framework of the CGE model.

3.1.1. Relationship between Production Activity and Water Resource Demand. The added value equation adopts the Cobb-Douglas form, assuming the constant returns-to-scale ratio:

$$\mathrm{VA}_j = A_j L_j^{\alpha_j} K_j^{1-\alpha_j}, \tag{1}$$

where VA_j represents the added value of the output of department j, A_j represents the production efficiency coefficient, α_j is the labor substitution elasticity of the j department, and L_j and K_j represents the labor and capital input of the j department, respectively.

3.1.2. Water Demand

$$W_j = VA_j * f_j, \tag{2}$$

where W is the water demand, f is the energy consumption level per unit added value in industrial sectors, and j represents the sector.

3.1.3. Water Resource Tax

$$TW = \sum_j tw_j * W_j, \tag{3}$$

where TW is the resource tax and tw is the tax rate.

3.1.4. Relationships between Climate Change and Economy. In the CGE model, the negative impacts of climate change on production will finally be reflected in the industrial sectors. This paper assumes that the direct destructive effects of climate change on productivity will affect the agricultural sector and will not cause direct and destructive effects on the productivity of other industrial sectors. However, it will be transmitted to other industrial sectors through the relationship of industrial chain in the CGE model and it constitutes an indirect destructive effect of climate change on the productivity of other industrial sectors except agriculture. In the equation system of CGE model, equation (1) is modified into equation (4), and the impact of climate change on the total economic output is regarded as the result of the decline of the total factor productivity under the same factor input. In the CGE model, the impacts of climate change on the economic output can be calculated in view of the exogenous impacts on the total factor productivity.

$$\mathrm{VA}_j = \overline{A_j} \cdot L_j^{\alpha_j} \cdot K_j^{1-\alpha_j}, \tag{4}$$

$$\overline{A_j} = \Omega_j \times A_j = \frac{1}{1 + \left(D_{0,j}/9\right) T_t^2} A_j, \tag{5}$$

where $D_{0,j}$ is the GDP loss caused by the temperature rise of 3°C and T_t represents the temperature t of the period.

3.1.5. CGE Dynamic Impact Process. Considering the long-term impacts of climate change on the economic system, the core mechanism of the dynamic process of the CGE model in this paper is the Solow economic growth model, which is an economic growth model within the framework of neoclassical economics with the production function in the form of Cobb-Douglas production.

$$K_{j.t+1} = \mathrm{Is}_{j,t} + \left(1 - \delta_j\right) K_{j.t}, \tag{6}$$

where $K_{j,t+1}$ is the capital stock of $t+1$ period, $\mathrm{Is}_{j,t}$ is the investment supply of the t period, $K_{j,t}$ is the capital stock of the t period, and δ_j is the capital depreciation rate.

Since the investment comes from the total economic output, its capital has the characteristics of continuous iteration as it forms the stock. As the future economic growth is closely related to the total economic output, economic losses due to the climate change can be reflected in future periods. The dynamic mechanism of the CGE model is used to describe the dynamic and continuous impacts of climate change on economic growth.

In addition, this paper also takes into account the labor force growth and technological progress (improvement of total factor productivity). The growth rate of the labor force and total factor productivity has a gradual downward trend, which is characterized by the following equation:

$$\begin{aligned}\frac{\dot{A}_t}{A_t} &= a \times e^{bt},\\ \frac{\dot{L}_t}{L_t} &= l \times e^{mt}.\end{aligned} \tag{7}$$

3.1.6. CO_2 Emission Calculation Process. The CO_2 emissions are calculated based on the energy, and the energy consumption structure of each industry is composed of the coal, oil, natural gas, and nonfossil energy:

$$\begin{aligned}S_{i,t} &= \left(C_{i,t}, P_{i,t}, G_{i,t}, \mathrm{NF}_{i,t}\right),\\ S_{i,0} &= \left(C_{i,0}, P_{i,0}, G_{i,0}, \mathrm{NF}_{i,0}\right),\end{aligned} \tag{8}$$

where $S_{i,0}$ is the energy structure of industry i in the base period; $C_{i,0}$, $P_{i,0}$, $G_{i,0}$, and $\mathrm{NF}_{i,0}$ are the sharing ratio of the coal, oil, natural gas, and nonfossil of the total in any base period of i industry; and t stands for time.

The energy use of each industry can be calculated on the basis of the energy demand factor for each sector and the sector's total output.

$$E_{i,k,t} = a_{i,k,t} X_{i,t}, \tag{9}$$

where $E_{i,k,t}$ stands for the amount of energy k in sector i for the t period and $a_{i,k,t}$ is the energy intensity in sector i for period t.

Carbon emissions are calculated at the sector level, which are based on the sector's energy consumption and energy carbon emission coefficient:

$$C_t = \sum_i \sum_{k=C,P,G} E_{i,k,t} \beta_k, \tag{10}$$

where β_k stands for the carbon emission coefficient of coal, oil, and natural gas.

3.2. Data and Scenarios. The data used in the research mainly comes from the *Annual Bulletin on Water (2000-2020)* and the project title *"Research on water use efficiency of high water consumption industries"* done by the China Academy of Water Resources and Hydropower Science (IWHR) (seen Figure 4), [32, 33]. In 2020, China's total water consumption was 581.29 billion cubic meters and the water used for citizen's daily use, industry sector, agricultural sector, and the ecological sector takes accounting for 14.9%, 17.7%, 62.1%, and 5.3%, respectively [34]. We address the industry sectors rather than the agriculture sector is due to the following reason: even if the water in the agriculture sector shares the most of the water consumption, it is not encouraged to tax from agriculture or farmers; as in China, the agricultural tax was abolished already.

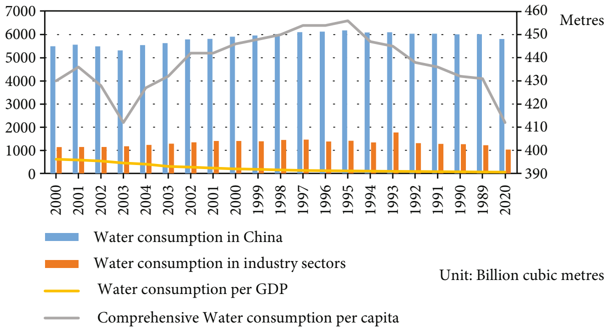

Figure 4: Water consumption in China from 2000 to 2020.

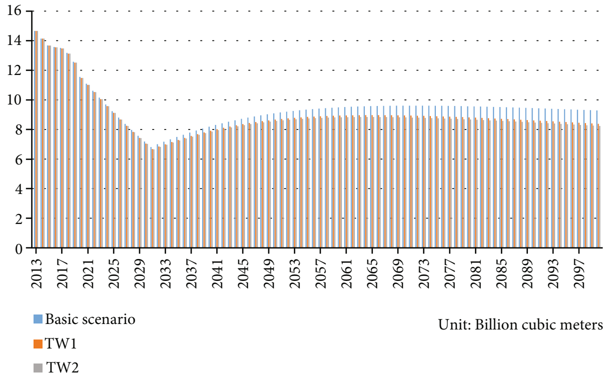

Figure 5: Water consumption in different scenarios in China from 2013 to 2100.

Two scenarios of tax have been set, and the tax ratios are 5 Yuan/m^3 and 10 Yuan/m^3, respectively. Current water price in the industry sector in Beijing is around 9 Yuan/m^3, and we assume the tax 10 Yuan/m^3. Based on the data of 2012, 10 Yuan/m^3 can take account for around 30% of the value-added tax, which is the high tax scenario. The tax ratio of 5 Yuan/m^3 is selected to be a comparative scenario.

The data which we used for the CGE model, such as the intermediate input, the initial input of labor and capital in various sectors, the gross domestic product of goods sold in the domestic market, the gross domestic product of goods imported, the consumption of household goods, the consumption of government goods, the final demand for investment, and the export good, are calculated by using the data

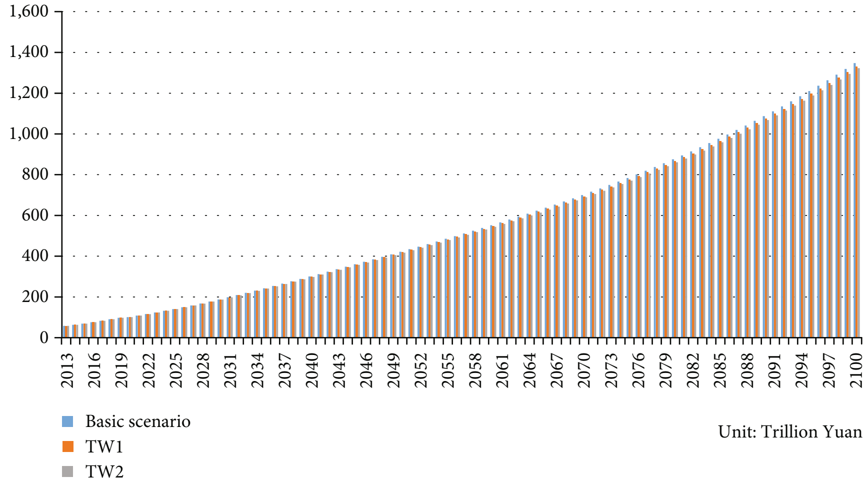

Figure 6: GDP in different scenarios in China from 2013 to 2100.

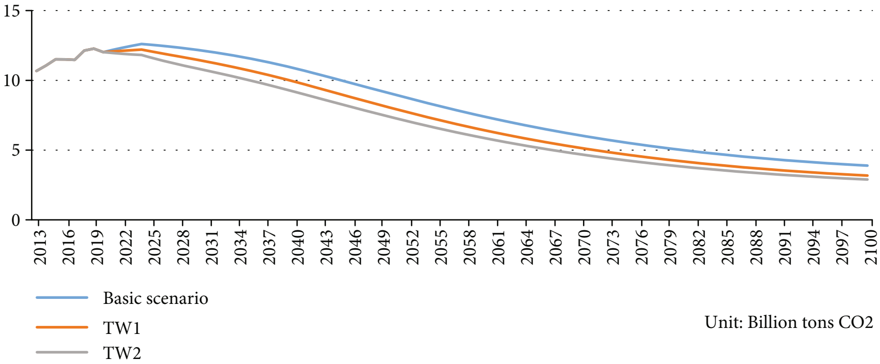

Figure 7: CO_2 in different scenarios in China from 2013 to 2100.

from the input-output table of the Chinese Economy in 2017 [35]. Other data are from the *China Statistical Yearbook* and *the Finance Yearbook of China.*

According to China's water utilization plan, the total water consumption will be controlled within 800 billion cubic meters and the water efficiency will reach the world's leading level by 2030. Meanwhile, the water consumption of 10000 yuan industrial added value will be reduced to less than 40 cubic meters, and the effective utilization coefficient of farmland irrigation water will be increased to more than 0.6 [34]. In 2020, water consumption per added value in industry sectors will be reduced to less than $40\,m^3/10000$ Yuan and continue to decline in the future. It is assumed that by 2030, it will reach the world's leading level and will remain constant in the following years. Therefore, according to the calculation of historical data, the following equation of the water consumption level per 10000 Yuan is used for future projection.

$$f_{i,t} = \begin{cases} 122.09e^{-0.099t}, & t \leq 23, \\ f_{i,23}, & t > 23. \end{cases} \tag{11}$$

When $t = 0$, it is the year of 2007. It is the time when the data can be used for projection with a significant trend.

4. Results and Analysis

4.1. Impacts on Water Resources and the Macroeconomy. As we can see from Figure 5, the water consumption in China reduces from 2013 to 2031 when the tax policy is implemented in 2020. After the turning point in 2031, the curve starts to rise smoothly and then becomes flat.

For the projection (shown in Figure 6), GDP in different scenarios are increasing in a steady upward trend from 2013 to 2100. The water tax implemented in the two scenarios are both acceptable as even in the high ratio of 10 Yuan/m^3.

4.2. Impact on CO_2 Emissions and Climate Change. As we can see from Figure 7, CO_2 emissions in three scenarios from 2013 to 2100 are shown, indicating that both the two tax ratios will do certain contribution to CO_2 reduction. At the beginning, CO_2 emissions will keep an increasing trend, and in the year 2030, CO_2 starts to reduce as targeted. However, based on our calculation, even in the high tax ratio

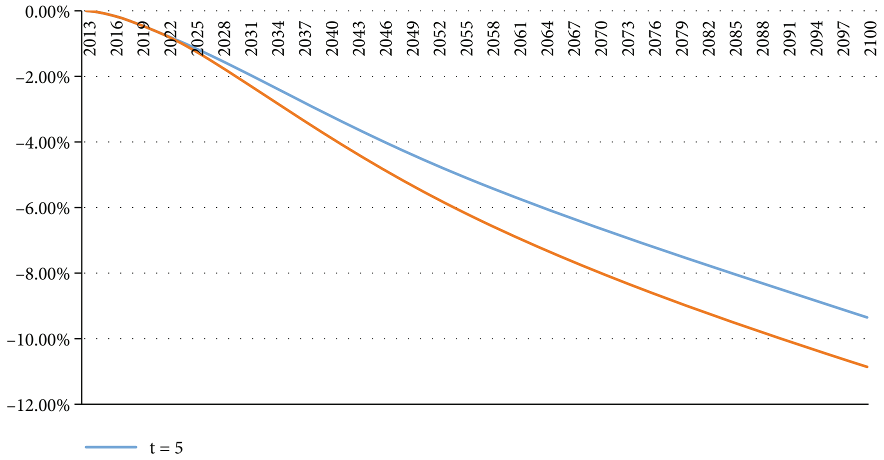

Figure 8: Tax impacts on the output of the high water intensity sectors in different scenarios in China from 2013 to 2100.

scenario, the policy impacts on both CO_2 emission and climate change in long term are tiny.

4.3. Impacts on High Water Intensity Sectors. The industrial water will also become the core of water management. We focus on the high water intensity sectors, which include the thermal power sector, the iron and steel sector, the chemical sector, the paper sector, the textile sector, the petroleum and petrochemical sector, the food sector, and the nonmetallic mineral product sector. The tax can impact those sectors greatly as time goes by (Figure 8), which is expressed by using the indicator of " changes of the value-added of the water-intensity industry divided by the total GDP change."

5. Conclusion and Discussion

In recent years, the Chinese government has successively issued the "National Water Resources Comprehensive Plan" (2010) and "The State Council's Opinions on Implementing the Most Strict Water Resources Management System" (2012) to raise water resources management to the national strategic level. Macropolicy control, specific water resource management measures, optimizing the allocation of water resources, strengthening water conservation, and achieving the goal of changing the wasteful and inefficient water use behaviors contribute, to building a water-saving society. The 13th Five-Year Plan further clearly states that "implement the most stringent water resources management system, use water to determine production, use water to determine the city, and build a water-saving society."

As we can see from the simulation, the linkage between industries under the CGE simulation can propose implications for decision makers, which indicates that the future focus should not be on water consumption or energy consumption in a certain region, and the transfer of resource pressures between industries should be addressed. In addition, policies such as taxation can also play an advantage in encouraging synergistic policies and guide those enterprises to update new technologies through measures such as the tax reduction or the tax exemption.

Water tax policy in different scenarios in China was simulated by using the CGE model in order to see a macropolicy impacts on the long-term climate change. As China has set the goal of peaking CO_2 emissions and achieving carbon neutrality, there is a need to notice that the process of those policies have a synergistic effect towards the CO_2 reduction, even the impacts are tiny. The CGE model is always used for the policies related with the economic system, and in the future, it may play more roles in the interdisciplinary; as in the next decades, the human will change nature through different actions by impacting the whole economic system and society.

Data Availability

The data used in the research mainly comes from the Annual Bulletin on Water (2000-2020) and the project title "Research on water use efficiency of high water consumption industries" done by the China Academy of Water Resources and Hydropower Science (IWHR).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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