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ENERGY-RELATED ECONOMIC MODELING TO SUPPORT THE ENVIRONMENTAL POLICY-MAKING, CASE STUDY OF THE PROVINCE OF SASKATCHEWAN

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Abstract: Recently, global climate change has emerged as one of the most challenging environmental issues and has gained considerable attention worldwide. Canada targets to achieve an economy-wide emissions objective by 2030. Facing these challenges, the Province of Saskatchewan is actively seeking effective way in order to realize GHG emission reduction targets in the most economical efficient manner. The objective of this study is to develop a systematic approach to gain more insights into the energy-environment-economy system and support the related policy-making. The systematic approach is composed of two models. In detail, Environmentally-Extended Input-Output (EEIO) Model is developed to facilitate the analysis of direct and indirect GHG emissions, emission relationships of different industries, as well as the integrated emission performance of the system. A Saskatchewan Computable General Equilibrium (SK-CGE) Model is developed to simulate a series of direct and indirect socio-economic impacts of various environmental policies. This research provides direct support for the environmental policy-making in Saskatchewan. The Environment Minister held a press conference to announce the modeling results and how they were used for formulating provincial carbon mitigation policies. The systematic approach is expected to be applied in other areas in Canada.

1 PROJECT OVERVIEW

Saskatchewan's economy is strengthening and the recent budget was designed in part to improve competitiveness. Along with growth are increasing greenhouse gas (GHG) emissions, which present conflicting economic and environmental challenges. Facing challenges to reduce barriers to growth, the Government of Saskatchewan is exploring how to accomplish GHG emission reduction targets in the most economically efficient manner.

At present, some existing policies such as technology improvement, industry GHG emission regulation, and carbon pricing, are capable of reducing GHG emissions and reaching environmental targets. However, these policies may hinder economic development to varying extents. To more fully realize sustainable development goals, a systematic evaluation of the emission intensity and total emissions of industries is indispensable for understanding the energy and environmental performance in general and to support scientific-based climate change policy-making.

Supported by the Natural Sciences and Engineering Research Council (NSERC), Canada Research Chairs Program, and the Government of Saskatchewan, this project aims at developing a systematic approach to gain more insights into the energy-environment-economy system and support the related policy-making.

2 METHODOLOGY

2.1 Environmentally-Extended Input-Output Model

An EEIOS model is developed to facilitate the analysis of GHG emission intensities of different industries, integrated GHG emissions and emission relationships of different industries, and impact analysis of Production-Based Policy (PBP) and Consumption-Based-Policy (CBP).

The two main inputs of the model are I-O tables and the emission factors of various emission source sectors. According to the analysis objectives, the I-O table should be aggregated and disaggregated to fit the environmental satellite accounts. The disaggregation method should be chosen based on data availability and sector characteristics to ensure the accuracy of model inputs. The emission factors of different energy sources vary due to region and utilization. In-depth surveys and research are thus needed to obtain the emission factors for one specific region. After data collection and processing, detailed analysis and comparative analysis can be conducted to reveal the emission intensities of various industries and the interactions among them. After simulating PBP and CBP for all industries, a Production-Consumption Rate (PCR) value will be calculated to identify the most efficient policy for each industry. Then, an optimized policy can be proposed based on the simulation results.

The EEIO model is based on the Leontief framework. The EEIO framework is outlined as follows.

$$x_{\mathrm{i}} = \sum_{j=1}^{N} z_{\mathrm{ij}} + f_{\mathrm{i}} \quad \text{for i} = 1 \text{ to } N \tag{1}$$

$$x_{\mathrm{i}} = \sum_{j=1}^{N} a_{\mathrm{ij}} x_{\mathrm{j}} + f_{\mathrm{i}} \quad \text{for i} = 1 \text{ to } N \tag{2}$$

$$\mathbf{E} + \boldsymbol{\varepsilon}\mathbf{Z} = \boldsymbol{\varepsilon}\mathbf{X} \tag{3}$$

$$\boldsymbol{\varepsilon} = \mathbf{E}[\mathbf{X} - \mathbf{Z}]^{-1} \tag{4}$$

$$\mathbf{IE} = \boldsymbol{\varepsilon}\mathbf{Z} \tag{5}$$

$$TE_i = IE_{ji} + E_i \tag{6}$$

where x_i is the total output of ith sector; z_{ij} is the amount of good i that sector j consumes; f_i is the final demand of ith sector; a_{ij} is the units of good i to produce 1 unit of good j; $\mathbf{E}$ is the direct emissions matrix; $\mathbf{IE}$ is the indirect emissions matrix; $\boldsymbol{\varepsilon}$ is the embodied emissions coefficient matrix; $\mathbf{Z}$ is the value flow matrix in the I-O table; IE_{ij} represents the indirect flows of sector j from sector i; E_i represents the direct emissions of sector i to the environment; TE_i is the total emissions of sector i; $\mathbf{X} = [x_{ij}]_{n \times n}$, when $i = j$ and $x_{ij} = x_i$, when $i \neq j$ and $x_{ij} = 0$.

2.2 Saskatchewan Computable General Equilibrium Model

In order to support the development of climate change regulations, various policy-induced general welfare impacts need to be simulated and compared. As is well known, Computable General Equilibrium (CGE) models are a class of economic models that use actual economic data to estimate how an economy might react to changes in terms of policy, technology or other external factors. Therefore, a Saskatchewan Computable General Equilibrium (SK-CGE) model was developed to achieve better simulation results.

The SK-CGE model was developed on the basis of data mentioned above. Generally, it comprises product module, trade module, income and expenditure module, social welfare module, equilibrium module, and policy module. The production module describes the ways in which capital, labor, energy, and intermediate inputs can be used to produce outputs. This module is represented by nested separable linear homogeneous constant elasticity of substitution (CES) production functions. In the trade module, given types of commodities are both exported and imported simultaneously. To address the two-way trade problem, the Armington assumption has been adopted by treating imported commodities and domestic commodities as differentiated products. For domestic goods and imports, the CES utility function has been used to determine their domestic demands, as shown in the following equations.

$$QX_i = \alpha_i^a \left(\delta_i^a F_i^{\frac{\sigma-1}{\sigma}} + \left(1-\delta_i^a\right) E_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{7}$$

$$QQ_j = \alpha_j^q \left(\delta_j^q QM_j^{-\rho_i^q} + \left(1-\delta_j^q\right) QD_j^{-\rho_j^q} \right)^{\frac{1}{\rho_j^q}} \tag{8}$$

$$QT_k = \alpha_k^t \left(\delta_k^t QE_k^{\rho_k^t} + \left(1-\delta_k^t\right) QD_k^{\rho_k^t} \right)^{\frac{1}{\rho_k^t}} \tag{9}$$

where QX_i represents total output; α_i^a represents a scale parameter in the CES activity function; δ_i^a represents a CES activity function share parameter; QQ_j represents the composite supply; α_j^q represents a scale parameter in the CES utility function; δ_j^q represents a CES utility function share parameter; QM_j represents the imported commodities quantity; QD_j represents the domestic commodities quantity; QT_k represents the composite supply; α_k^t represents a scale parameter in the CES utility function; δ_k^t represents the CES utility function share parameter; QE_k represents the exported commodities quantity; QD_k represents the domestic commodities quantity.

3 RESULT ANALYSIS

3.1 Industrial GHG Mitigation Policy Analysis

The total GHG emissions of all sectors in the Province of Saskatchewan is 251.9 Mt, with the direct and indirect GHG emissions being 74.8 Mt and 177.1 Mt respectively. The indirect emissions are 2.4 times the direct emissions, which shows the significance of indirect emissions.

The total GHG emissions of Services sector is the highest, followed by the Household Consumption sector, Agriculture and Forestry sector, and Crude Oil Extraction sector. In the contrast, the total GHG emissions of Coal Mining sector is relatively low, as well as the Natural Gas Extraction sector, and Other Manufacturing sector. When only considering direct emissions, the GHG emissions of Crude Oil Extraction sector, Agriculture and Forestry sector, and Electric Power Generation, Transmission and Distribution sector rank at the top, which has relatively low indirect emissions. It is worth noting that a majority of GHG emissions of Services sector are indirect emissions, which contribute 96 percent of its total GHG emissions. Household Consumption sector has the next highest indirect GHG emissions. These sectors can be classified into two categories based on their total GHG emission performance. Five sectors emit more direct GHG emissions, including the Agriculture and Forestry sector, Crude Oil Extraction sector, Natural Gas Extraction sector, Electric Power Generation, Transmission and Distribution sector, and Transportation and Warehousing sector. The other eight sectors emit more indirect GHG emissions, which is closely correlated to their industrial characteristics and production structures. In other words, production activities for a primary industry are more likely result in direct GHG emissions, while indirect GHG emissions are most likely to happen in secondary and tertiary industries.

An optimized GHG mitigation strategy can be made by implementing different policies on different industries based on the PCR values. There are four industries with PCR values for three kinds of emissions higher than one. Therefore, PBP will be applied in these four industries in the optimized scenario. By comparing with the other ten industries, it can be seen that the PCR values of three kinds of emissions of other four industries are all much lower than one, illustrating that CBP should be adopted in the optimized scenario. What's more, the emissions of the eight industries rank at the top of the entire system, which are considered as the critical industries in the Province of Saskatchewan. The optimized emission reduction policy scenario based on the PCR analysis has a better performance in regard to direct emissions, indirect emissions, and total emissions.

3.2 Carbon Tax Impacts Analysis

Using the CGE model developed in this paper, the implications of a carbon tax on total GHG emission reduction and GDP change were calculated. It is seen that the carbon tax has opposite impacts on economic growth and emission reduction.

When carbon tax is under C$ 30 (i.e. scenario 1 and 2), the GDP change is relatively low. This indicates that a relatively low carbon tax won't significantly impact the economy. In scenarios 3 and 4, the GDP decreases faster when the carbon tax continues to grow. When carbon tax reaches C$ 40/tonne, which is the carbon tax rate proposed by the federal government, the GDP will decrease by 0.96%. The GDP will decrease sharply with a carbon tax equal to C$50/tonne. Considering that the GDP improvement of the Province of Saskatchewan was approximately 2% in 2015, the GDP change for scenario 5 would be considered unacceptable.

The GHG emission will reduce significantly with the application of a carbon tax. For example, the GHG emissions will reduce by 7.3%, which is 4.8 million tonnes of emissions, when the carbon tax rate is C$40/tonne. There is no doubt that a carbon tax is an effective way to reduce the GHG emissions. It is also worth noting that the GHG emission reduction rate is increasing along with the carbon tax rate. However, both environmental and economic targets should be considered simultaneously. Comparing the impacts on GDP and GHG emissions, the effects of a carbon tax on GHG emission reduction is less obvious than the effects of a carbon tax on GDP change.

4 CONCLUSIONS

This study firstly developed an EEIO model to facilitate industrial GHG mitigation policy-making from both production and consumption perspectives and a SK-CGE model to explore the impacts of various economy-wide GHG mitigation policies. This is the first study to conduct an in-depth and comprehensive analysis with regard to carbon tax impacts on the socio-economic system of Canada. The model structure is based on a practical economic structure and energy utilization conditions. In addition, Different types of GHG emissions (i.e. CO_2, CH_4, and N_2O) from various emission sources (i.e. gas, oil, coal, and other) are considered in this study to reveal the differences among the above options.

It is found that all emission sources and GHG types should be considered to comprehensively identify the characteristics of emissions flows in the socio-economic system. Production activities for a primary industry are more likely to result in direct GHG emissions, while indirect GHG emissions are most likely to occur in secondary and tertiary industries. The Production-Based Policies applied to the primary industries will cause larger emission reductions in the system, since the primary industries affect other industries through intermediate utilization. In contrast, it is recommended to apply the Consumption-Based Policies to the industries that are located at the end of industrial chains.