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Development of a global computable general equilibrium model coupled with detailed energy end-use technology

Shinichiro Fujimori [a,*], Toshihiko Masui [a], Yuzuru Matsuoka [b]

[a] Center for Social and Environmental Systems Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[b] Department of Urban and Environmental Engineering, Kyoto University, 367, C1-3, Kyoto-Daigaku Katsura Campus, Nishikyo-Ku, Kyoto city, Kyoto 606-8540, Japan

HIGHLIGHTS

- Detailed energy end-use technology information is considered within a CGE model.
- Aggregated macro results of the detailed model are similar to traditional model.
- The detailed model shows unique characteristics in the household sector.

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ABSTRACT

A global computable general equilibrium (CGE) model integrating detailed energy end-use technologies is developed in this paper. The paper (1) presents how energy end-use technologies are treated within the model and (2) analyzes the characteristics of the model's behavior. Energy service demand and end-use technologies are explicitly considered, and the share of technologies is determined by a discrete probabilistic function, namely a Logit function, to meet the energy service demand. Coupling with detailed technology information enables the CGE model to have more realistic representation in the energy consumption. The proposed model in this paper is compared with the aggregated traditional model under the same assumptions in scenarios with and without mitigation roughly consistent with the two degree climate mitigation target. Although the results of aggregated energy supply and greenhouse gas emissions are similar, there are three main differences between the aggregated and the detailed technologies models. First, GDP losses in mitigation scenarios are lower in the detailed technology model (2.8% in 2050) as compared with the aggregated model (3.2%). Second, price elasticity and autonomous energy efficiency improvement are heterogeneous across regions and sectors in the detailed technology model, whereas the traditional aggregated model generally utilizes a single value for each of these variables. Third, the magnitude of emissions reduction and factors (energy intensity and carbon factor reduction) related to climate mitigation also varies among sectors in the detailed technology model. The household sector in the detailed technology model has a relatively higher reduction for both energy intensity and the carbon factor.

1. Introduction

Integrated Assessment Models (IAM) are widely used in climate mitigation analysis. For example, the following models are all well-known IAMs: AIM/CGE [1], GCAM [2], IMAGE [3], MESSAGE [4], and ReMIND [5,6]. These models more or less couple economy, energy, GHG emissions, agriculture, land use, and climate components. If the scope is broadened to not only this type of large-scale IAM but also to simple energy models, there are many more examples. One is the Asian Modeling Exercise [7], which compiles the results of 23 models. Although there is no clear definition, energy models are generally classified into two types depending on how they represent energy technologies: the so-called bottom-up (BU) type model, which has a detailed representation of energy technologies, and the top-down (TD) type model, which uses either a production function or price elasticity to represent aggregated energy technologies. Furthermore, there are two classes of TD type models depending on the extent to which goods are dealt with. One is the computable general equilibrium (CGE) model, which covers all goods and services transactions, whereas the other is known as the Partial Equilibrium (PE) model, which treats specific goods

* Corresponding author. Tel.: +81 29 850 2188.
E-mail address: Fujimori.shinichiro@nies.go.jp (S. Fujimori).

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(e.g., energy goods). AIM/CGE, EPPA [8], and IMACRIM-R [9] are classified as CGEs, and GCAM [1] and TIMER (which is a part of a module within IMAGE) [10] are PEs. There are many studies using CGE models if the models are not limited to IAMs (e.g. [11–13]).

The advantages of BU models are the disadvantages of TD models and vice versa. TD models are easily able to represent the heterogeneity of energy technology selection in non-linear functions, but the representation of energy technology is aggregated and it is difficult to assess whether the solutions are feasible from a technological point of view. In addition, TD CGE models deal with all of the transactions for goods and production factors. They can assess the responses of the macro-economy and the prices of all goods to interventions, such as a carbon emissions constraint. The BU model can simulate more realistic technological descriptions of energy and assess the technological feasibility of climate mitigation targets. BU models, however, are usually linear to minimize total costs and the cheapest single technologies are chosen without extra constraints even if actual consumer behavior would not be as extreme.[2]

Several studies have tried to complement each type model's advantages and disadvantages. MESSAGE did this with MESSAGE-MACRO [14], and CIMS [15] maintains overall consistency by exchanging information with a macroeconomic module.

Previous studies using the CGE model have not fully integrated the BU structure within it. CGE is generally a large-scale model, and two methods have been used to account for both TD and BU. One is to prepare a BU model outside of the CGE model and exchange information with the BU model more than one time. Drouet et al. [16] and EPPA [17] input the outcomes of a BU model into energy consumption functions in the household and the transport sectors, respectively. IMACRIM-R exchanges the output information with a BU model iteratively for all sectors. Another way to integrate TD and BU models is to deal with detailed energy technologies within the TD model but focus only on a specific sector. Many studies have disaggregated electricity sectors [18–20]. However, most such studies have treated only specific sectors and have not expanded to other sectors. Moreover, exchanging information with a BU model does not guarantee a consistent solution with a convergence.[3] If the first method can be expanded to other sectors, the results would be quite informative because both the economic and technological sides will be represented consistently. Furthermore, it could potentially improve the representation of reality as well as the reliability of the CGE model analysis.

In this context, a CGE model integrating detailed technological information not only for the electricity sector but also for energy end-use sectors is proposed in this study with two objectives: (1) to demonstrate how to integrate detailed BU information within a CGE model and (2) to understand the characteristics of the model behavior.

Section 2 presents the model structure for both types of models. In one, energy is represented by a traditional aggregated function, and in the other, energy is represented by detailed BU information. In Section 3, the scenario framework and assumptions are explained necessary to determine the characteristics of the proposed model. To test the model differences, two scenarios with and without climate change mitigation are implemented. Section 4 presents the model results, focusing on how the results differ for the two types of model. In Section 5, the discussions are made on the interpretation and the implications of the results, and limitations of this type of modeling. Finally, concluding remarks are shown in Section 6.

2. Methodology

2.1. AIM/CGE basic model structure

The AIM/CGE model has been widely used for the assessment of climate mitigation and impact (e.g., [1,21]). The CGE model used in this study is a one year step recursive-type dynamic general equilibrium model that covers all regions of the world. This model includes 17 regions and 42 industrial classifications (see Tables A1 and A2) for lists of the regions and industries). A characteristic of the industrial classifications is that energy sectors, including power sectors, are disaggregated in detail. Moreover, to assess bioenergy and land use competition appropriately, agricultural sectors are also highly disaggregated. This CGE model is based on the "Standard CGE model" [22]. Details of the model structure and mathematical formulas are described by Fujimori et al. [23].

The production sectors are assumed to maximize profits under multi-nested Constant Elasticity Substitution (CES) functions and each input price. Energy transformation sectors input energy and value added as fixed coefficients of output. They are treated in this manner to appropriately deal with energy conversion efficiency in the energy transformation sectors. Power generation values from several energy sources are combined with a Logit function [18]. This method is adopted in consideration of energy balance since the CES function does not guarantee a material balance. Household expenditures on each commodity are described by a Linear Expenditure System (LES) function.[4] The saving ratio is endogenously determined to balance saving and investment, and capital formation for each good is determined by a fixed coefficient. The Armington assumption is used for trade, and the current account is assumed to be balanced.

In addition to energy-related CO_2 emissions, CO_2 from other sources, CH_4, and N_2O are treated as GHG emissions in this model. The non-energy related CO_2 emissions consist of land use change and industrial process. CH_4 has various sources, but main sources are rice production, livestock, fossil fuel mining and waste management sectors. N_2O is emitted by the application of fertilizers, livestock manure management and chemical industry. The energy related emissions are associated with the fossil fuel consumption and combustion in the model. Non-energy related emissions other than land use change emissions are assumed in proportion to the level of activities (such as output). Land use change emissions are derived from the difference of forest land area from that of previous year multiplying the carbon stock density.

In this paper, climate change mitigation scenarios are dealt with (the scenario framework will be shown in Section 3.1). The implementation of the mitigation is represented by putting global total emissions constraint. Once emission constraint is put on, the carbon tax becomes a complementary variable to that constraint and determines marginal mitigation cost. This tax makes the price of fossil fuel goods higher when emissions are constrained and promotes energy savings and the substitution of fossil fuels by lower emission energies. The carbon tax is an incentive to reduce the non-energy related emissions also. Other than CO_2 gases are weighted by global warming potential and summed up as total GHG emissions. The revenue from this tax is assumed to be received by households.

[1] In some cases, GCAM can be classified as an integrated BU and TD model.

[2] Some BU models are not necessarily linear models and such models can deal with heterogeneity of the consumer choices by using non-linear function. GCAM is one of the examples.

[3] If the exchanging information is aggregated indicators, it would not be so hard to get convergence. However, the detailed information exchange makes hard to do so.

[4] The parameters adopted in the LES function are recursively updated in accordance with income elasticity assumptions.