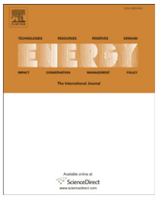
Energy 114 (2016) 293–301

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



Global energy model hindcasting

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

[a] *Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), 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 606–8540, Japan*

ARTICLE INFO

Article history:
Received 8 July 2015
Received in revised form
1 August 2016
Accepted 2 August 2016

Keywords:
Hindcasting
Validation
Computable general equilibrium model
Integrated assessment models

ABSTRACT

This paper performs energy model hindcasting which compared the historical energy simulation results with the observations. We used one of the Integrated Assessment Models and simulated global historical energy consumption from 1981 to 2010 associated with exogenous socioeconomic assumptions, as is typically performed for future scenario. The simulation period was chosen with consideration of data availability and structural constancy of the model. Based on comparison with observations, there are three main findings. First, the global aggregated primary energy shows high reproducibility. In terms of energy source specific results, the fitness in electricity, coal, and biomass consumption were high. However, that of crude oil and natural gas is lower than others. This could be due to the price elasticity assumption, implying that the model can be improved with regard to this element. Second, the reproducibility increases as the simulation is close to the base year 2005. Third, although the global aggregated information shows high reproducibility, some disaggregated regions have lower reproducibility. Furthermore, high income countries tend to show higher reproducibility than in low income countries. Given the uncertainties in the ability of IAMs to reproduce certain aspects of the energy system, forecasts must be treated with caution.

1. Introduction

Integrated assessment models (IAMs) are commonly used for long-term global climate mitigation analysis [1–5]. IAMs typically couple economic, energy, greenhouse gas (GHG) emissions, agricultural, land use, and climate components. Because the energy related GHG emissions is the major sources, the energy component (or module) is a key element that determines the reliability of the future projection and policy assessment to a large extent. In the past few decades, policy decisions have been increasingly reliant on IAM's outcomes, and the model reliability has been questioned. There are multiple approaches to evaluate reliability of IAMs [6]. One is the so-called diagnostics approach, which tests model behaviors under specific hypothetical assumptions, such as carbon price pathways. The ultimate goal is to increase our understanding of differences in model behavior, enable fingerprinting of model responses, and classify models based on their fingerprints [7]. Another is to publicize model detail documentation with the goal of increasing the transparency of the models, which has been accomplished in the ADVANCE project (Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies) [8].

Hindcasting is considered one approach for examining do validation but focused on the uncertainty caused by different calibrations of the model, have been performed using IMAGE/TIMER (The IMage Energy Regional model) model [9,10]. They used Monte-Carlo simulations for a low-income country's building and transport sectors, and proposed the methodology for estimating parameters to better capture historical patterns. Furthermore, they explicitly point out how different calibrations can lead to very different future projections. Another relevant study is validated the volatility of oil prices based on assumptions of oil production [11]. With respect to the land use and agricultural goods model, there is also a study about the hindcasting [12].

For more typical model validation methodology, econometrics have also been applied [13]. They focused on the US, and similar attempts have been made for other OECD countries. However, this method requires adequate and sufficient time series data as input to estimate the function forms and parameters. In terms of the

---

[*] Corresponding author.
E-mail address: fujimori.shinichiro@nies.go.jp (S. Fujimori).

http://dx.doi.org/10.1016/j.energy.2016.08.008
0360-5442/

global scale model, information on the energy price, capital price, and all of the input information (such as energy, capital, and labor) for individual sectors is limited. In that context, the econometric method would not be the ideal solution for the global energy model validation. Other earlier studies had limitations in their coverage of either sectors or regions.

Based on these previous studies, this study performed a global historical energy consumption simulation using the AIM/CGE (Asia-Pacific Integrated Models/Computable General Equilibrium) model which has been widely used for the climate change mitigation and impact assessment. Overall, this paper aims to identify the AIM/CGE model elements that have low reproducibility and to make suggestions regarding future research. For example, it is expected to answer in what sectors and regions there are large discrepancies between observations and model simulation. This work contributes to the previous studies by incorporating global and all sectors of energy consumptions into hindcasting model. It should be noted that many conditions must be fulfilled to deduce the reproducibility of the historical model simulation for the future. More specifically, this paper performed the model simulation under specific GDP, population, and other technological and preference assumptions over the short-term (less than 30 years) or the scenarios in which we can expect constancy in the model structure. Hence, the outcome of this study should be interpreted as one of the model validations only for model projections that do not greatly differ from the historical development pattern (the structure is not greatly changed) and for a relatively short period. Such conditions and how to interpret the results are discussed in the final section in greater detail.

2. Methods

2.1. Overview of the methods

AIM/CGE was used for historical simulations and the analytical period was from 1981 to 2010. AIM/CGE is commonly used for the climate change mitigation and impact assessment at both global and national scales [14–21]. Because the social accounting matrix (SAM) is only available for the base year of 2005, the simulation was not performed from past to present but from the base year to the past. The period from 2006 to 2010 was performed in the same way as future scenarios. Finally, the simulation results were compared to the observations. Data availability (energy and price observations) is the primary criteria for the selection of the period of study.[1]

2.2. AIM/CGE model

2.2.1. Overview of the AIM/CGE model

The AIM/CGE model used in this study is a recursive-type, dynamic, general equilibrium model that covers all regions of the world. The production sectors are assumed to maximize profits under specific production functions and each input price. The income generated by production activities is received by the representative household. The household saves parts of the income for investment and spends the remainder in purchasing goods and services to maximize utility under specific utility functions. The saving ratio is endogenously determined to balance saving and investment, and capital formation for each commodity is determined based on a fixed coefficient. The trade is treated as homogenous but is differentiated from domestic goods. The current account is balanced. Details of the model structure and mathematical formulas are provided by AIM/CGE manual [22] and the main model structure and equations primarily related to energy consumption are provided in Supporting Information Section 1.

2.2.2. Production function and its energy consumption

The production function is basically formulated as a multi-nested constant elasticity substitution (CES) function, but is differentiated among energy transformation sectors and energy end-use sectors. Energy transformation sectors consume energy goods and value-added as a fixed coefficient (Leontief function) to ensure energy conversion efficiency. This suggests that energy consumption in a sector is determined based on its output multiplied by a coefficient. Energy end-use sectors can substitute energy and value-added with a constant elasticity. The CGE approach for energy modeling typically incorporates autonomous energy efficiency improvement (AEEI), which represents energy technological improvements unrelated to price change. The AEEI effect is considered by multiplying coefficients to the energy consumption branch, which is only applied to the energy end-use sectors. In contrast to CES function by many other CGEs, in this model the energy composition is determined based on its logit function [23] to maintain the energy balance. In summary, the price elasticity and AEEI assumptions are key parameters for energy consumption in industrial sectors.

Power generation from several energy sources are combined using a logit function, although a CES function is commonly used in other CGE models. We chose this method for the consideration of energy balance because the CES function does not guarantee an energy balance [24]. The value added is aggregated from labor and capital inputs.

2.2.3. Household behavior and energy consumption

Household expenditures on each commodity are described using a linear expenditure system (LES) function. The parameters adopted in the LES function are recursively updated in accordance with income elasticity assumptions. Thus, energy consumption in a household is mainly determined based on an assumption on the income elasticity for energy goods. There are two goods directly relevant to household energy consumption. One is energy consumption for private car usage and the other is the remaining energy consumption, such as space heating. Both total energies are determined based, mainly, on total household expenditure and energy prices. Energy source compositions are then determined based on the logit functions associated with the energy price. Traditional biomass usage is explained by population and AEEI.

2.2.4. Parameter settings for energy determinants

This sub-section explains the key parameter settings that are primary determinants of energy consumption. First, as explained previously, energy input in energy end-use sectors are determined based on the CES nested function with the elasticity substituted between value added and energy, where the elasticity is assumed to be 0.4 [25]. Next, the AEEI is changed as a function of GDP growth. In principle, the AEEI is high when a country has a high GDP growth rate, whereas it is low in low GDP growth areas [10]. If GDP growth is negative, AEEI is fixed as zero. If GDP growth ranges from 0 to 3%, 3–5%, and over 5%, annual AEEI is assumed to be 1%, 1.5%, and half of the GDP growth percentage, respectively. The AEEI should differ across energy sources to reflect the energy consumption composite switch from coal to oil, gas, or electricity. Therefore, a coefficient to the logit component (Equation (14) in Supporting Information) is multiplied. Coal, gas, and electricity are assumed to have 1%, −0.5%, and −1% annual changes. Because previous studies did not report these values, these numbers are arbitrarily assigned. The AEEI for the traditional biomass usage was

---

[1] The simulation prior to 1980 going back to 1970 has also been tried but the strong oil price shock in 1970s made the model infeasible.