Considering the Timing of Updating Social Accounting Matrices and Energy Data in CGE Models for Quantifying Mitigation Scenarios

Osamu Nishiura [a]*
[a] Social System Division, National Institute for Environmental Studies (NIES), City of Tsukuba, Japan
* Corresponding author, E-mail address: nishiura.osamu@nies.go.jp

Keywords
Computable General Equilibrium model, Social Accounting Matrix, Energy balance table, climate change mitigation

1. Introduction

To avoid the severe and irreversible impacts of climate change, large-scale and rapid reductions in greenhouse gas (GHG) emissions and CO2 removals (CDRs) are needed worldwide. Mitigation scenario research quantifies measures to achieve the long-term temperature target set out in the Paris agreement and their impacts on the energy system, economy, and land use, contributing to the formulation of climate policy. Mitigation scenarios are often quantified using economic, energy, and land-use models, either singly or in integration. Among models used to quantify mitigation scenarios, dynamic CGE models have provided important information for the formulation of climate policy by estimating macroeconomic losses from climate change mitigation and changes in goods prices and household consumption due to their detailed representation of sectors and goods. CGE models are generally calibrated to their base year using the social accounting matrices (SAMs). Many global CGE models use the Global Trade Analysis Project (GTAP) Data Base to calibrate their models [1-5]. Many models also use the International Energy Agency's (IEA) Energy Balance Tables in addition to the GTAP Data Base to refine their energy system representations [1-3]. It is ideal for CGE models to be calibrated to the most recent year, avoiding non-stationary years such as large-scale natural disasters, financial crises, and pandemics. However, model development resources and other factors limit the frequency of SAM updates. Some models are calibrated using the most recent GTAP year currently available [5]. However, some models are still calibrated using the 2004 SAMs [1].

GTAP 12 Data Base include reference years 2004, 2007, 2011, 2014, 2019, and 2023 [6]. The IEA Energy Balance Tables compile energy data through 2022 [7]. This period includes several events that had a significant impact on the economy and energy consumption, such as the global financial crisis and pandemics. It also saw mitigation efforts progress in some countries and regions. The purpose of this study was to provide information to assist in considering the frequency and timing of updating SAMs and energy data in CGE models used to quantify mitigation scenarios. To this end, the economy and energy information used to calibrate the AIM-Hub model were updated using GTAP 12 Data Base and the IEA Energy Balance Tables, allowing for reproducing the historical trend from 2005 to 2022. The updated model estimated mitigation scenarios that achieve the 1.5°C target with altered calibration period for energy and economic data.

2. Methods

This study analyzed how the mitigation scenarios change when the calibration period for its energy and economic parameters was set to five different periods (2005 - 2007, 2011, 2014, 2019, and 2022) in the AIM-Hub model. The AIM-Hub model is a recursive dynamic CGE model with 2005 as the base year [5]. The AIM-Hub model uses GTAP Data Base to construct its SAM and refines the energy system representation using the IEA Energy Balance Table.

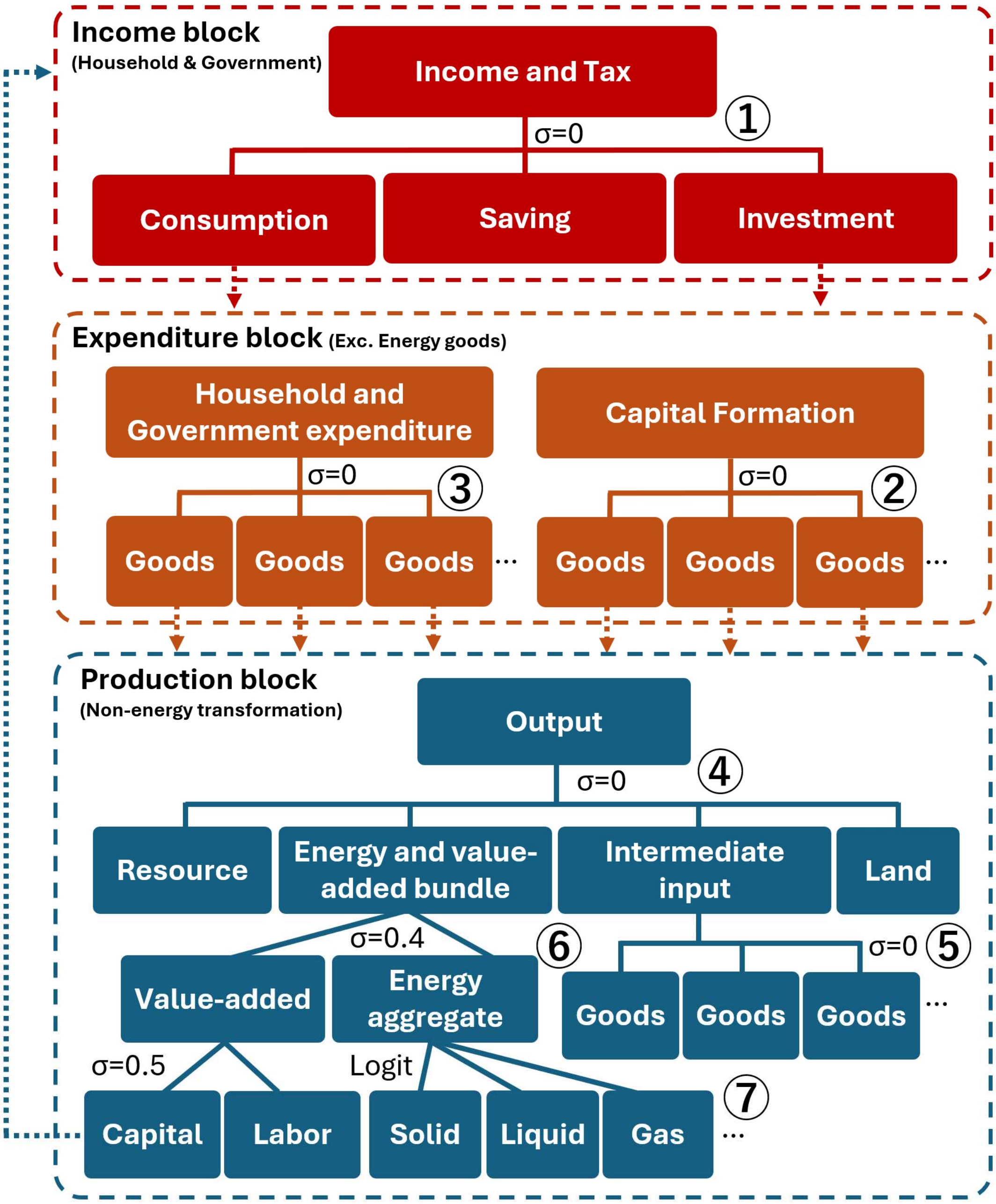

Figure 1. Overview of AIM/Hub model structure

In the AIM-Hub model, the production and consumption of goods are represented using multiple functions (Figure 1). Income from capital and labor is used for investment up to an amount exogenously set based on GDP growth rate, with the remainder used for consumption and savings (1). Household consumption is represented by the linear expenditure system (LES) demand functions, and capital formation is represented by the Leontief function (2-3). The production activities of each sector to meet the demand for each good calculated using these functions are represented by the multi-nested constant elasticity of substitution (CES) function (4-7). The composition of resources, energy and value-added bundles, intermediate inputs, and land, and the composition of intermediate inputs, are represented by the CES function with elasticity 0, i.e., the Leontief function. Since the above functions (1-5) are not elastic to the prices of goods and production factors, the parameters of the functions determine the share of expenditure on goods and production factors. In the AIM-Hub model, the parameters of these functions have been set based on the 2005 SAM and scenario assumptions (GDP, etc.). In this study, we adjusted the parameters of these functions to reproduce the values in the GTAP 12 Data Base. The AIM-Hub model calculates energy and value-added bundles using the CES function, and the composition of energy goods using the Logit function (6-7) considering autonomous energy improvement. When calibrating the model's energy parameters, the share parameters in the CES and Logit functions are adjusted to reproduce the values in the IEA Energy Balance Table. After the energy parameter calibration, the AIM-Hub model adjusts the share parameters to reflect autonomous improvements in energy efficiency. After the calibration period, this energy efficiency improvement rate is set exogenously based on the GDP growth rate for each region specified in the scenario.

We created scenarios combining the calibration periods (2007, 2011, 2014, 2019, 2022) and the presence or absence of CO_2 emission constraints after 2025 (BaU, Miti) (Table 1). In the mitigation scenario, an emission pathway was set to limit cumulative CO_2 emissions to less than 500 Gt-CO_2 to achieve the 1.5°C target. Socioeconomic scenarios were set based on the `Middle of the Road` in the Shared Socioeconomic Pathways (SSP2). Population and GDP up to 2025 were set based on observed values.

Table 1. Scenario description

Scenario	Calibration period	Mitigation target
BaU_2007	2004 - 2007	NA
BaU_2011	2004 - 2011	NA
BaU_2014	2004 - 2014	NA
BaU_2019	2004 - 2019	NA
BaU_2022	2004 - 2022	NA
Miti _2007	2004 - 2007	1.5°C target
Miti _2011	2004 - 2011	1.5°C target
Miti _2014	2004 - 2014	1.5°C target
Miti_2019	2004 - 2019	1.5°C target
Miti_2022	2004 - 2022	1.5°C target

3. Results

This chapter presents the preliminary results of scenario estimation using the AIM-Hub model after updating only energy data. All scenarios accurately reflect historical changes in GDP because they use the same exogenous GDP. By calibrating energy-related coefficients through 2022, the BuU_2022 scenario accurately reflects changes in energy demand due to the global financial crisis and pandemic (Figure 2). The other scenarios partially reflect the impact of these events through changes in GDP. Scenarios that calibrated energy-related coefficients to more recent years projected a larger energy demand in 2025 than other scenarios. Using BaU_2022 as the base, the different scenarios projected a maximum decrease of 7.4% in energy demand in 2025. The decrease in energy demand was particularly pronounced in Asia and the Africa/Middle East region, where the differences between the BaU_2022 scenario and the other scenarios were up to 21.0% and 19.6%, respectively. In the OECD+EU region, scenarios calibrating to more recent years projected smaller energy demand, contrary to the global trend. In Asia and the Africa/Middle East region, energy efficiency improvements after calibration were assumed to be higher, whereas in the OECD+EU region, they were assumed to be lower than the actual data. CO2 emission factors were not updated in this data update. However, the BuU_2022 scenario generally traced past trends. Although scenarios calibrating energy coefficients to more recent years projected higher energy demand in 2025, CO2 emissions did not show a similar trend. In particular, in the OECD+EU region, scenarios calibrate to more recent years projected lower CO2 emissions in 2025.

In the current model update, the parameters related to the demand of each good have not been adjusted, resulting in differences between the GTAP12 value-added and AIM-Hub value-added calculation results. In the AIM-Hub model, the change in share from 2005 to 2025 was monotonic. This is because, without parameter adjustments, the value-added share in the AIM-Hub model changes with the GDP growth rate. In the GTAP 12 Database, peaks were observed around 2017 for non-metallic minerals, iron and steel, and the chemical industry.

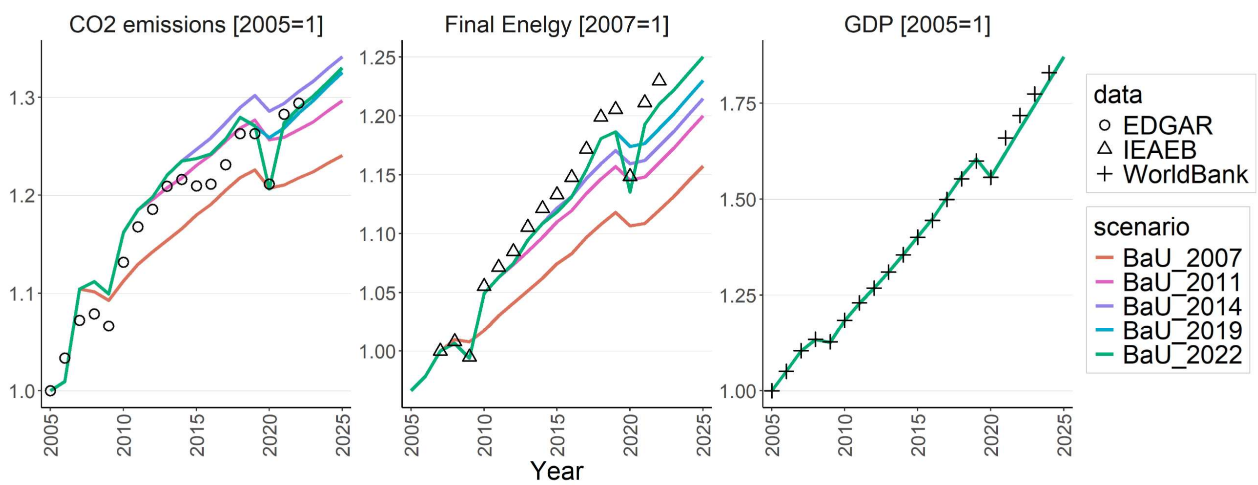

Figure 2. Variables related to model calibration

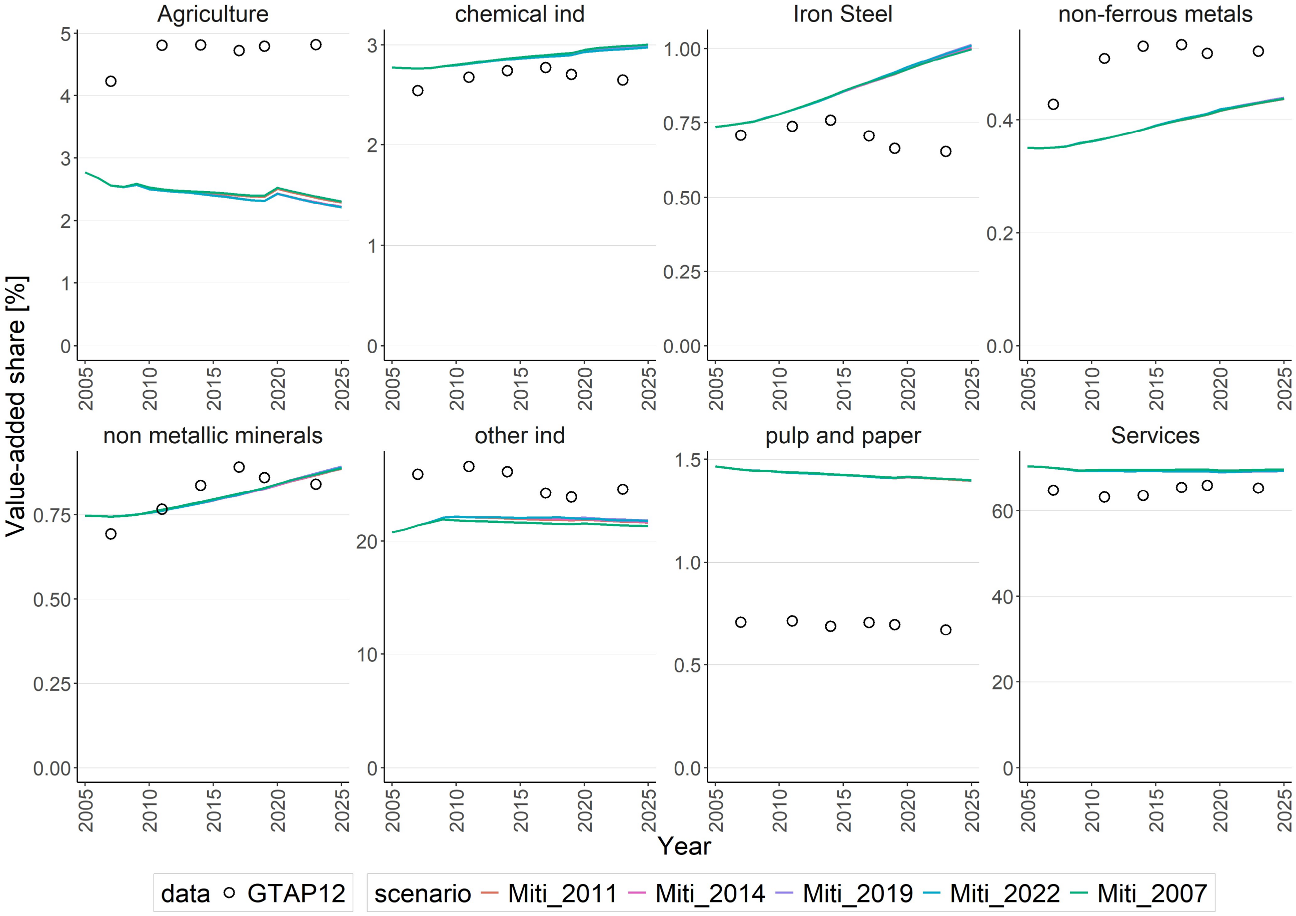

Figure 3. Value-added

Differences in the calibration period affected the estimated results of mitigation scenarios up to 2100 (Figure 4). Differences in final energy consumption between the scenarios continue, and the largest difference was 10.4% (between Miti_2007 and Miti2022) in 2100. The difference was huge in Asia, where it reached 23.6% (between Miti_2007 and Miti_2022). Unlike final energy consumption, the difference in global CO2 emissions between scenarios narrowed, especially in the second half of this century. This is due to the constraints imposed on global emissions. However, the regions that showed negative emissions in 2100 differed. In Miti_2007 and Miti_2011, emissions were negative in the OECD+EU and Middle East and Africa regions, while in Miti_2014, Miti_2019, and Miti_2022, emissions were negative in the OECD+EU and Asia regions. Globally, the difference in GDP losses between scenarios was not large. At the regional scale, in Asia, the maximum difference between scenarios was 12.4%, while in the OECD+EU region, the maximum difference was 40.6%.

Energy supply is also affected by differences in the calibration period in the models. Fossil fuel consumption in 2025 varied across scenarios, but the difference narrowed at the end of this century. The fossil fuel reduction rate from 2025 to 2035 ranged from 26.3% (Miti_2022) to 27.0% (Miti_2011), with minor differences across scenarios. The difference between scenarios for energy supply from renewable sources, excluding biomass, also narrowed in the second half of this century.

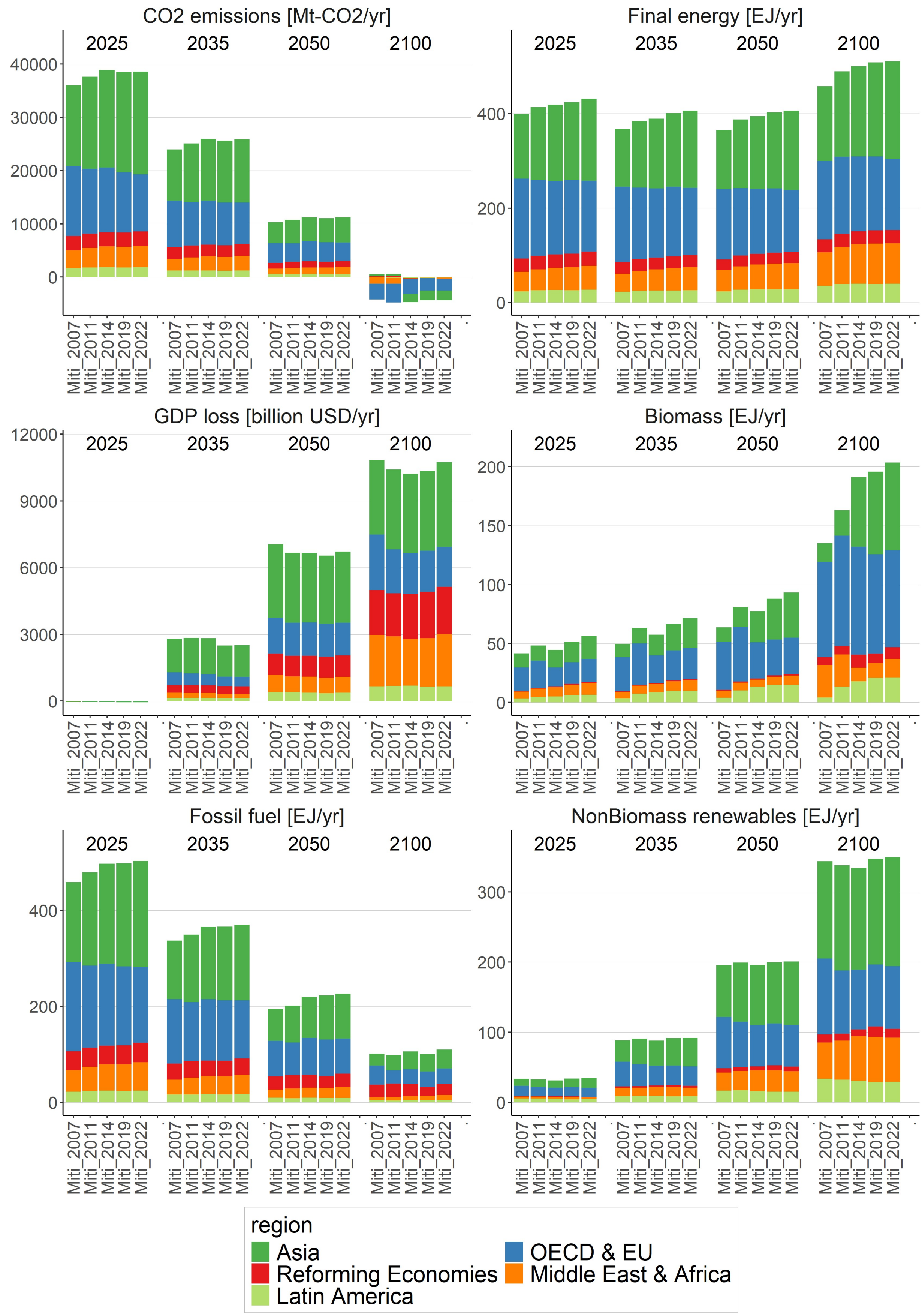

Figure 4. Mitigation scenarios with different calibration periods

The difference in biomass supply between the scenarios widened in the second half of this century. In 2100, the difference in biomass supply between the scenarios reached a maximum of 33%. The differences in biomass supply between the scenarios were large in Asia, the Middle East/Africa region, and South America, with the differences estimated at 78.9%, 73.1%, and 80.9%, respectively.

4. Summary

This study estimated five mitigation scenarios by varying the calibration period in the AIM-Hub model, a recursive dynamic CGE model, and compared the results to provide information to assist in considering the timing of updating SAM and energy data in CGE models used to quantify mitigation scenarios.

When the energy coefficients were calibrated to more recent years, an increasing trend in global energy demand in 2025 was observed. Regionally, this trend was observed in Asia and Middle East/Africa region. In mitigation scenarios up to 2100, significant differences were observed in the amounts of energy supply from biomass and CO2 removal across Asia and Middle East/Africa region, depending on the calibration period for the energy coefficients. Biomass can be used to provide low-emission liquid and gaseous fuels and to remove CO2 in combination with CO2 capture and storage. Due to their relatively high costs, these measures are implemented after the widespread adoption of inexpensive renewable energy sources such as solar and wind power, and the electrification of energy-consuming sectors. Therefore, biomass energy supply changed significantly in response to shifts in energy demand driven by changes in the calibration period. When using CGE models to analyze the impacts of mitigation measures on food production and ecosystems, it is essential to update energy data and the assumption of autonomous improvements in energy efficiency. Furthermore, changes in socioeconomic systems driven by economic growth and trade may explain differences in energy demand across calibration periods. Accurate analysis of these changes would require updating the SAMs. In the OECD+EU region, calibration to a more recent year showed a decrease in energy demand and a reduction in GDP loss due to emissions reduction. Part of the results is due to the reflection of recent mitigation efforts in this region.

In this draft, I updated only the energy data and compared the results, focusing on energy-related variables. In the future work, I plan to update the parameters related to economy and conduct analyses focusing on economic indicators such as commodity prices and household consumption. I then plan to compare the results from updating only energy data with those from updating both energy data and the SAMs.

Reference

[1] Fujimori S, Hasegawa T, Masui T. AIM/CGE V2.0: Basic feature of the model. Post-2020 Climate Action: Global and Asian Perspectives, Springer Singapore; 2017, p. 305–28. https://doi.org/10.1007/978-981-10-3869-3_13.

[2] Chen Y-HH, Paltsev S, Gurgel A, Reilly JM, Morris J. The MIT EPPA7: A Multisectoral Dynamic Model for Energy, Economic, and Climate Scenario Analysis | MIT Global Change. Joint Program Report Series Report 360, June, 54 p 2022. https://cs3.mit.edu/publication/17777

[3] Capros P, Denise VR, Leonidas P, Karkatsoulis P. GEM-E3 Model Manual. 2017. https://www.ricardo.com/media/zt4pgiyu/gem-e3_manual_2017.pdf

[4] Sands RD, Schumacher K, Förster H. U.S. CO2 Mitigation in a Global Context: Welfare, Trade and Land Use. The Energy Journal 2014;35:181–97. https://www.jstor.org/stable/26606201

[5] van der Mensbrugghe D. The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model. Version 10.4, 2024. The Center for Global Trade Analysis, Purdue University. https://www.gtap.agecon.purdue.edu/uploads/resources/download/12591.pdf

[6] Aguiar A, Baldos U, Chepeliev M, Corong E, & Simonato T. The Global Trade Analysis Project (GTAP) Data Base: Version 12. Journal of Global Economic Analysis, 10(2). https://doi.org/10.21642/JGEA.100201AF

[7] IEA, World Energy Balances, IEA, Paris https://www.iea.org/data-and-statistics/data-product/world-energy-balances