Response to Reviewer #1 Comments:

General Evaluation

This manuscript presents AIM-ALPHA v1.0, a global partial equilibrium model designed to simulate agricultural production, land use, trade, and prices, with explicit representation at national and river-basin levels. The model integrates supply, demand, and land allocation decisions across multiple commodities and regions, and is positioned as a tool for analyzing long-term interactions among agriculture, climate mitigation, and food security. The paper provides an overview of the model structure, core assumptions, and computational framework, and evaluates model performance against historical statistics. The authors demonstrate the model's application through a climate mitigation scenario and emphasize that fine spatial resolution allows the identification of distributional effects that are masked in more aggregated models. The use of a GAMS/MCP formulation and the provision of model code are also notable strengths, as they support transparency and reproducibility in principle.

Overall, the manuscript introduces a relevant and timely modeling framework, and the development of a basin-level, globally consistent partial equilibrium model represents a potentially valuable contribution to the literature. The model has clear potential applications in food security analysis, land-use policy assessment, and integrated climate-economy studies. The paper is generally well organized and provides substantial technical material. However, despite the ambitious scope and policy relevance of the framework, several aspects of the documentation, validation, and methodological transparency require further clarification and strengthening. In particular, more rigorous evaluation of model performance, clearer exposition of the underlying economic structure, and a deeper discussion of uncertainties and limitations are needed to enhance the credibility and usability of the model. Addressing these issues would substantially improve the manuscript's contribution to the GMD community.

> **Response:**
> We sincerely thank the reviewer for the thorough and constructive evaluation of our manuscript. We greatly appreciate the positive comments and the helpful suggestions for improving the documentation, validation, and explanation of the model structure. We have carefully considered all comments and revised the manuscript accordingly. Please see below our point-by-point responses.

Major Comments

(1) Positioning, Contribution, and Literature Coverage

The manuscript does not sufficiently situate AIM-ALPHA within the existing literature on spatially explicit partial equilibrium and land-use models. While MAgPIE and GLOBIOM are mentioned, other closely related modeling frameworks, such as GTAP-AEZ-RB, SIMPLE-G, and GTAP-SIMPLEG, are not discussed. Methodologically, AIM-ALPHA appears to share substantial similarities with the GTAP-AEZ and SIMPLE modeling traditions, particularly in its treatment of land heterogeneity, spatial disaggregation, and market equilibrium. In addition, the authors rely on USDA-based crop elasticities that are widely used in these existing models. Given these overlaps, the manuscript would benefit from a more systematic comparison with these frameworks. A more comprehensive literature review and explicit discussion of similarities, differences, and added value are needed to clarify the model's contribution.

Response:

We thank the reviewer for this comment. In the revised Introduction, we have expanded the literature review to cover GTAP-AEZ and related GTAP-based river-basin water extensions, SIMPLE-G, GTAP-SIMPLE-G, and IMPACT, in addition to MAgPIE and GLOBIOM. These models provide methodological precedents for AIM-ALPHA in their treatment of land heterogeneity, spatially disaggregated production, market equilibrium, and market-mediated land-use responses.

Line 48: "In addition to these global integrated assessment and land-use models, agro-economic modelling has also developed through spatially explicit partial- and general-equilibrium frameworks, including GTAP-AEZ (Lee et al., 2005) and related GTAP-based river-basin water extensions (Taheripour et al., 2013; Haqiqi et al., 2016), SIMPLE-G (Baldos et al., 2020), GTAP-SIMPLE-G (Wang, 2024), and IMPACT (Robinson et al., 2015)"

We also revised the contribution statement to position AIM-ALPHA as a complementary model combining country-level demand and trade representation, subnational river-basin production and land allocation, recursive-dynamic long-term scenario analysis, and consistency with the broader AIM framework.

Line 64: "Existing models emphasise different dimensions of this problem. For example, MAgPIE and GLOBIOM represent land-use processes at high spatial detail but commonly represent demand and market outcomes at aggregated multi-country or regional levels (Dietrich et al., 2019; IBF-IIASA, 2023). In contrast, national-level multimarket models such as IMPACT (Robinson et al., 2015) capture country-level agricultural markets and provide an important benchmark for food-security and agricultural market analysis, while placing greater emphasis on market and food-system outcomes than on explicit subnational land allocation. Related equilibrium-based frameworks, including GTAP-AEZ, GTAP-based river-basin water extensions, SIMPLE-G, and GTAP-SIMPLE-G, have made important contributions to representing land heterogeneity, spatially disaggregated production, and market-mediated land-use responses (Lee et al., 2005; Taheripour et al., 2013; Baldos et al., 2020; Wang, 2024). These frameworks demonstrate the value of linking agricultural market equilibrium with spatially differentiated land, water, and production systems, although they are generally oriented toward comparative-static or policy-shock analysis rather than recursive-dynamic long-term integrated assessment. However, to our knowledge, the combination of country-level demand and trade representation with subnational river-basin production and land allocation has not yet been implemented in a published recursive-dynamic model for long-term integrated assessment and land-use scenario analysis."

(2) Economic Representation

Figure 3 presents price on the horizontal axis and quantity on the vertical axis, which is inconsistent with standard economic conventions, where price is typically shown on the vertical axis. While this may seem minor, it raises concerns about the authors' familiarity with standard economic representations and modeling practices. The authors should ensure that the economic interpretation of the diagram is correct and consistent with the broader literature. More generally, the paper would benefit from stronger engagement with established economic modeling conventions.

Response:

We have revised Figure 3 so that price is shown on the vertical axis and quantity on the horizontal axis, and updated the caption and surrounding explanation accordingly.

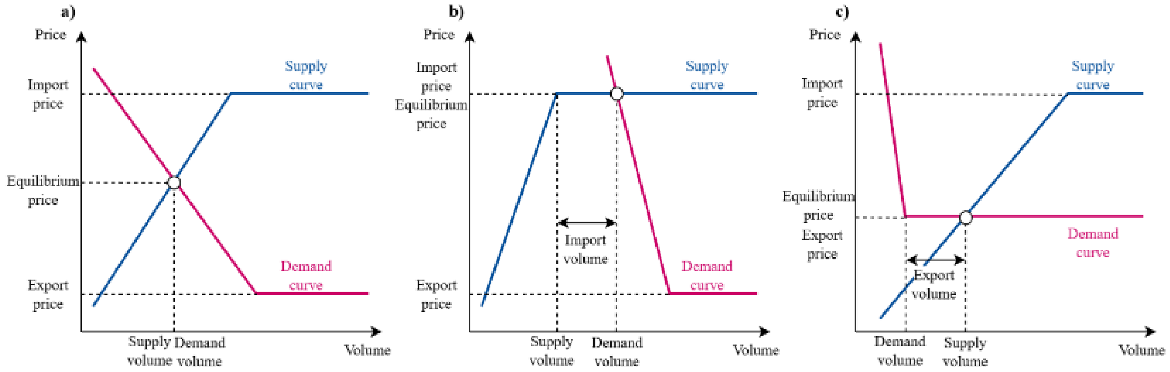

Figure 3. The trade mechanism in the model. Each panel shows the domestic supply and demand curves of a country: (a) no-trade regime, in which the domestic equilibrium price lies between the import and export price bounds; (b) import regime, in which the domestic price equals the import price and the supply–demand gap is met by imports; and (c) export regime, in which the domestic price equals the export price and the surplus is exported.

(3) Model Transparency, Documentation, and Structural Assessment

The manuscript provides extensive code and scripts, but very limited formal documentation of the model structure. There are essentially no explicit equations describing behavioral relationships, market-clearing conditions, or closure rules. As a result, it is currently impossible for reviewers and readers to evaluate the internal logic and structural consistency of the model. Without a clear mathematical representation, one cannot assess whether the implementation faithfully reflects the intended economic structure. For a GMD paper, this is a significant limitation. The authors should provide a formal description of the core model equations, including supply and demand systems, land allocation, trade representation, and equilibrium conditions. This is necessary to allow independent assessment and reproducibility. In future publications, you can refer to this paper for equations.

Response:

We have substantially revised Sect. 2 to include explicit equations and closure information for the core components of AIM-ALPHA.

The revised manuscript now includes mathematical descriptions of the demand system, production and input relationships, production-unit to country-level aggregation, producer-price identity, land-allocation structure, land-balance constraints, biophysical land constraints, international trade complementarity conditions, domestic and global market clearing, and the GHG mitigation and emissions module. A new Table 2 summarises the main endogenous variables, exogenous drivers, and closure rules for each model block, and the supplementary material provides the full set of equations, variable definitions, and implementation details.

(4) Baseline Replication and Validation

The main evidence for model validation appears to be Figure 10, which compares estimated values with historical FAOSTAT data. However, this comparison raises important concerns. The base year of the model is 2015. In standard partial equilibrium models implemented in GAMS using MCP formulations, the benchmark equilibrium should "exactly" replicate the base-year data when no shocks are applied. This is a fundamental property of calibrated equilibrium models. Figure 10 indicates substantial deviations between modeled and observed values even in the base year, with many observations falling outside narrow tolerance ranges. This suggests that the model does not properly replicate its calibration data. In many established modeling frameworks (e.g., GEMPACK, GAMS/MCP and MPSGE-based models), baseline consistency is routinely verified through numeraire checks and zero-shock simulations, which reproduce the reference dataset exactly. Deviations at the benchmark stage often indicate structural inconsistencies, coding errors, or incomplete calibration.

The authors should therefore: Explain why exact base-year replication is not achieved; Clarify whether the reported discrepancies arise from deliberate modeling choices or technical limitations; and provide additional diagnostic checks demonstrating numerical consistency. Without convincing evidence of proper benchmark replication, the credibility of scenario results is difficult to assess.

Response:

We thank the reviewer for this comment. We have revised Sect. 4.1.2 and Figure 10 to make this distinction explicit. In the revised manuscript, Figure 10 evaluates the model along two complementary dimensions. First, benchmark replication is assessed by comparing the zero-shock 2015 AIM-ALPHA solution with the internally harmonized calibration dataset used to initialize the model. This check confirms that the model reproduces its own calibration targets for the reported country–commodity variables within numerical tolerance. Second, we compare the model outputs with the original FAOSTAT observations as an external historical-data check.

Line 602: "Figure 10 evaluates the model from two perspectives: benchmark replication and comparison with original historical statistics. The benchmark-replication check assesses whether AIM-ALPHA reproduces its internally harmonised calibration dataset, whereas the FAOSTAT comparison evaluates agreement with the original historical observations. The calibration dataset is constructed by harmonising FAOSTAT with LUH2, GTAP, and spatial allocation datasets, and by applying consistency adjustments to production, demand, input use, prices, and land area. In the zero-shock benchmark simulation, AIM-ALPHA reproduces the internally harmonised 2015 calibration dataset for the reported country–commodity variables within numerical tolerance (Fig. 10a), confirming the consistency of the calibrated equilibrium.”

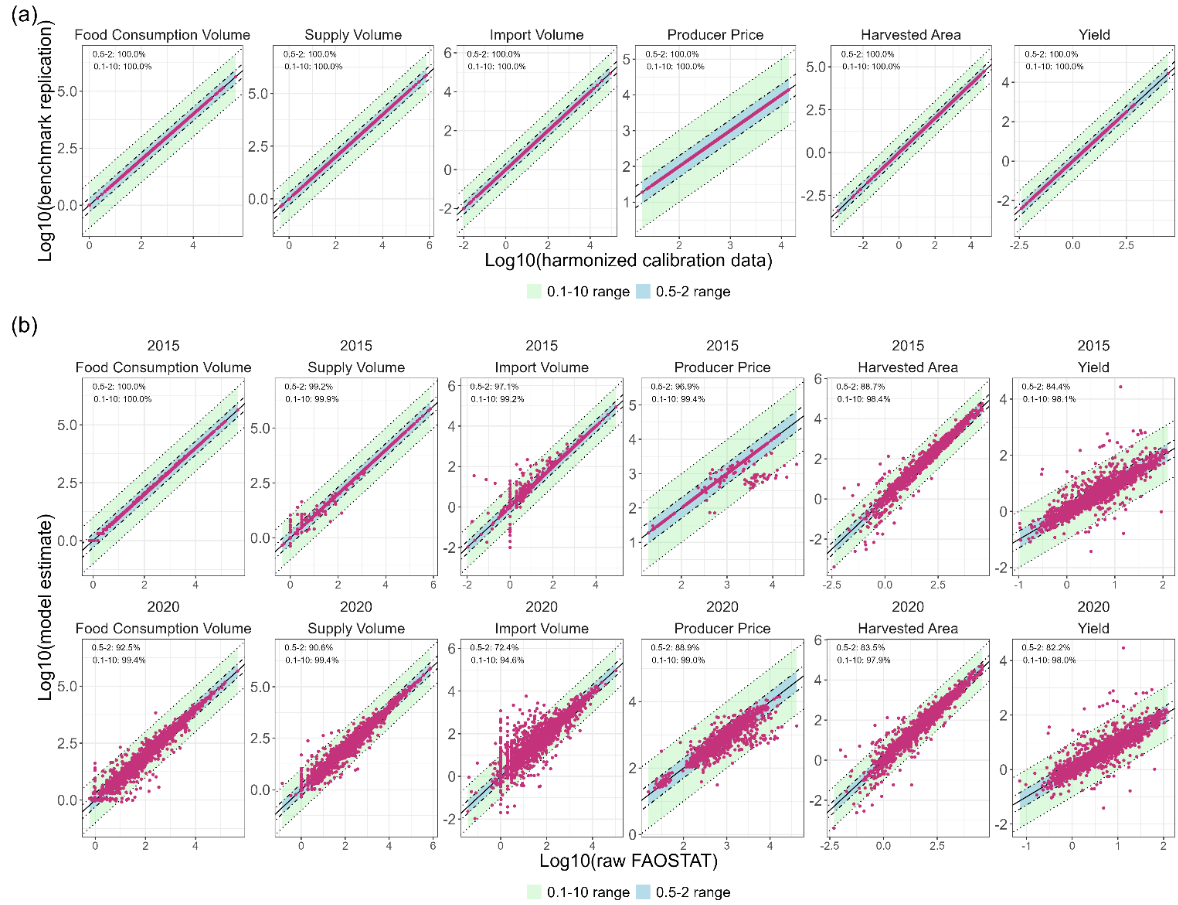

Figure 10. Benchmark replication and comparison with FAOSTAT for food consumption, supply, imports, producer prices, harvested area, and yield. Panel (a) compares the zero-shock AIM-ALPHA solution for the 2015 base year with the internally harmonized calibration dataset. Panel (b) compares the AIM-ALPHA estimates for 2015 and 2020 with FAOSTAT observations (FAO, 2025). Each point represents a country–commodity pair, and the estimated data are those of SSP2–BaU. The solid diagonal line denotes exact agreement, and the shaded bands indicate deviations within factors of 2 (0.5×–2×) and 10 (0.1×–10×). The percentages are the proportions of data points within each range.

We also clarified why the harmonized calibration dataset does not always exactly match raw FAOSTAT values. AIM-ALPHA combines FAOSTAT with LUH2, GTAP, and spatial allocation datasets, and applies data-harmonization procedures to ensure consistency among production, demand, feed and raw-material inputs, prices, land area, and equilibrium conditions. These procedures include corrections of inconsistent input–output records, treatment of producer-price outliers, and recalculation of yields using LUH-based land areas. Therefore, deviations from raw FAOSTAT in Figure 10b reflect data harmonization and external-data differences, rather than a failure of benchmark replication.

Line 608: “The FAOSTAT comparison (Fig. 10b) shows that 2015 food consumption and supply quantities are well aligned with the original observations, while discrepancies remain for harvested area and yield. These mainly reflect the use of harmonised land-area data and consistency adjustments during calibration, rather than direct adoption of FAOSTAT harvested-area and yield values.”

References

Baldos, U. L. C., Haqiqi, I., Hertel, T. W., Horridge, M., and Liu, J.: SIMPLE-G: A multiscale framework for integration of economic and biophysical determinants of sustainability, Environmental Modelling & Software, 133, 104805, https://doi.org/10.1016/j.envsoft.2020.104805, 2020.

Haqiqi, I., Taheripour, F., Liu, J., and Mensbrugghe, D. van der: Introducing Irrigation Water into GTAP Data Base Version 9, Journal of Global Economic Analysis, 1, 116–155, https://doi.org/10.21642/JGEA.010203AF, 2016.

Lee, H.-L., Hertel, T., Sohngen, B., and Ramankutty, N.: Towards An Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation, GTAP Technical Papers Archive, 2005.

Robinson, S., Mason-D’Croz, D., Sulser, T., Islam, S., Robertson, R., Zhu, T., Gueneau, A., Pitois, G., and Rosegrant, M. W.: The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3, https://doi.org/10.2139/ssrn.2741234, 26 November 2015.

Taheripour, F., Hertel, T. W., and Liu, J.: Introducing water by river basin into the GTAP-BIO model: GTAP-BIO-W, , https://doi.org/10.22004/ag.econ.283495, 2013.

Wang, Z.: GTAP-SIMPLE-G: Integrating Gridded Land Use, Crop Production and Environment Impacts into Global General Equilibrium Model of Trade, Journal of Global Economic Analysis, 9, 1–69, https://doi.org/10.21642/JGEA.090201AF, 2024.