# Responses to reviewers' comments

- Reviewer comments are in blue, regular font.
- Author responses are in black, regular font.
- *Updated manuscript texts are in purple, italic font.*

## Anonymous Referee #1

The manuscript presents GCAM-China-v8, an updated China-focused version of GCAM with provincial-level representation and enhanced sectoral detail. The model is potentially valuable for the integrated assessment modeling community and for studies of China's long-term energy and emissions pathways. However, several aspects of the manuscript require further clarification before publication.

**Author's response:** We thank the reviewer for the constructive comments. We have revised the manuscript to (i) explicitly compare GCAM-China-v8 with earlier versions and related applications, (ii) add a new section on scenario design and model calibration procedure, and (iii) clarify the representation and limitations of water accounting, electricity trade, and non-$CO_2$ mitigation.

1. The abstract states that GCAM-China-v8 includes enhanced sectoral and temporal representations (Line 59), but these two improvements are not sufficiently highlighted in the subsequent model description. The authors should clearly identify what has been improved in sectoral resolution and temporal representation relative to previous GCAM-China versions.

**Author's response**: We agree with this comment and revise the Abstract to highlight the key features documented in GCAM-China-v8. Furthermore, we have revised Section 2.2 Previous GCAM applications and model development in China (Table 1), Section 2.3 "Overview of GCAM-China" to distinguish between features inherited from earlier GCAM-China development and those updated in the GCAM-China-v8 open-source release.

***Revised text:***

***Abstract:*** *"This paper documents the model structure and data inputs of GCAM-China-v8, with particular emphasis on the major methodological and data updates introduced in this open-source release. Specifically, GCAM-China-v8 updates the base-year calibration from 2015 to 2021, represents coal-fired power generation technologies by construction vintage, adds a provincial water supply and demand module, and introduces a provincial policy module illustrated through a nuclear power incentive policy case."*

***Section 2.2 Previous GCAM applications and model development in China (Table 1):***

*Table 1 Representative China-focused GCAM-based models, coupled frameworks, and GCAM-China model-family developments*

<table>
<tr><th>Model/ Framework</th><th>Version</th><th>Base year</th><th>Spatial resolution</th><th>Sectoral coverage & technology detail</th><th>Temporal structure</th><th>Model coupling</th><th>Openness</th><th>Policy representation and typical applications</th></tr>
<tr><td>GCAM-TU</td><td>GCAM 4.0</td><td>2010</td><td rowspan="4">National (China)</td><td>Detailed industry, buildings, and transport; EOP control technologies</td><td rowspan="6">5-year time steps to 2100</td><td rowspan="4">—</td><td rowspan="4">Core GCAM open</td><td>National mitigation; energy–air pollution co-control(Wang et al., 2016)</td></tr>
<tr><td>GCAM</td><td>GCAM 6.0</td><td>2015</td><td>Detailed power sectors; China-specific data and parameters</td><td>Carbon-neutrality pathways; sectoral transitions; technology dynamics(Pan et al., 2023, 2022)</td></tr>
<tr><td>GCAM-TU-Hydrogen</td><td>GCAM v7.0</td><td>2015</td><td>$H_2$ production, transport, distribution, and end use; interregional $H_2$ trade</td><td>$H_2$ supply and demand; technology adoption; international trade(Zhang et al., 2024)</td></tr>
<tr><td>GCAM-CHN</td><td>GCAM v7.0</td><td>2015</td><td>Expanded subsectors; fossil CCS, BECCS, and DACCS</td><td>CCS deployment; technology uncertainty (Shao et al., 2025)</td></tr>
<tr><td>CNCAP</td><td>GCAM-China v4.3</td><td>2010; DPEC harmonized to 2015</td><td rowspan="2">Provincial (31 provinces)</td><td>Emission-source technologies; fleet turnover; EOP controls</td><td>GCAM-China + MEIC + DPEC</td><td rowspan="2">Used in published studies; method, selected inputs/scenarios/results available depending on study</td><td>Emission projections; climate–clean-air co-control; health assessment (Tong et al., 2020; Cheng et al., 2021, 2023)</td></tr>
<tr><td>GCAM-China-ABaCAS</td><td>GCAM-China; v4.3</td><td>2010; calibrated for 2010/2015</td><td>Detailed emission sectors and technologies; localized emission factors; EOP controls</td><td>GCAM-China + ABaCAS-EI + CMAQ</td><td>Air-quality attainment; climate–clean-air co-benefits; health impacts (Xing et al., 2020; Dong et al., 2024; Sun et al., 2024)</td></tr>
</table>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *GCAM-China-v6* | *GCAM-China v6* | *2015* | | *Province-level energy-economic representation; building sector split by urban/rural households; national biomass market; provincial $CH_4$ and $N_2O$ emissions from resource and agriculture sectors; wind/PV represented without province-specific supply curves* | | | *Fully open: code, inputs, scenarios, outputs* | *Provincial mitigation pathways; energy-system transitions; sectoral and regional policy analysis(Deng et al., 2025; Kim et al., 2024; Lou et al., 2025; Wang et al., 2025; Yin et al., 2026a; Yu et al., 2019, 2020)* |
| *GCAM-China-v7* | *GCAM-China v7* | *2015* | | *GCAM-Macro coupling added;*<br><br>*high-resolution provincial wind and PV supply curves;*<br><br>*building sector disaggregated by urban/rural households and income group; provincial biomass markets; provincial $CH_4$ and $N_2O$ emissions from energy, resource, and agriculture sectors* | | *—* | | *Provincial mitigation pathways; energy-system transitions; national policy analysis* |
| *GCAM-China-v8(this study)* | *GCAM-China v8* | *2021* | | *Current documented release;*<br><br>*inherits earlier province-level GCAM-China capabilities; adds endogenous subnational water supply and demand; construction-vintage-specific coal-fired power technologies; province-level policy specification* | | | *Open-source release documented in this study; code, input data, scenarios, outputs, and documentation provided* | *Provincial mitigation pathways; energy-system transitions; sectoral and regional policy analysis;* |

***Notes:*** *EOP denotes end-of-pipe emission control; MEIC denotes the Multi-resolution Emission Inventory for China; DPEC denotes the Dynamic Projection model for Emissions in China; ABaCAS-EI denotes the ABaCAS emission inventory; CMAQ denotes the Community Multiscale Air Quality model; GCAM-China-v6 and GCAM-China-v7 are listed to indicate major capabilities established during earlier GCAM-China development. GCAM-China-v8 is the current open-source release documented in this study and consolidates inherited capabilities with additional updates.*

***Section 2.3 Overview of GCAM-China*****:** *"Several model features documented in this study were originally developed in earlier GCAM-China versions, including provincial wind and solar PV* *resource supply curves, building-sector disaggregation by income, biomass markets, and energy-sector non-CO2 emissions. GCAM-China-v8 builds on these prior developments by harmonizing the implementation with the core GCAM v8.2 framework and by updating, consolidating, and documenting key features in the open-source release. Major updates include updating the calibration year from 2015 to 2021, endogenizing subnational water supply and demand, disaggregation of coal-fired power generation technologies by construction vintage, and adding a provincial policy module."*

2. The consideration of vintage-specific existing power infrastructure, particularly coal-fired power units, appears to be an important methodological improvement. This contribution should be emphasized earlier in the manuscript, for example in the abstract, introduction, or model overview.

**Author's response**: Thank you for your suggestion. We have revised the Abstract, Introduction, and the Section 2.3 Overview of GCAM-China to highlight the disaggregation of coal-fired power generation technologies by construction vintage as a key update in GCAM-China-v8.

***Revised text:***

***Abstract:*** *"This paper documents the model structure and data inputs of GCAM-China-v8, with particular emphasis on the major methodological and data updates introduced in this open-source release. Specifically, GCAM-China-v8 updates the base-year calibration from 2015 to 2021, represents coal-fired power generation technologies by construction vintage, adds a provincial water supply and demand module, and introduces a provincial policy module illustrated through a nuclear power incentive policy case."*

***Introduction, the fourth paragraph：*** *"It incorporates several methodological updates, including an updated base-year calibration from 2015 to 2021, disaggregation of coal-fired power generation technologies by construction vintage, endogenous representation of water supply and demand at the subnational scale, and added provincial policy module with example representation of nuclear power incentive policy."*

***Section 2.3 Overview of GCAM-China：*** *"Several model features documented in this study were originally developed in earlier GCAM-China versions, including provincial wind and solar PV resource supply curves, building-sector disaggregation by income, biomass markets, and energy-sector non-CO2 emissions. GCAM-China-v8 builds on these prior developments by harmonizing the implementation with the core GCAM v8.2 framework and by updating, consolidating, and documenting key features in the open-source release. Major updates include updating the calibration year from 2015 to 2021, endogenizing subnational water supply and* *demand, disaggregation of coal-fired power generation technologies by construction vintage, and adding a provincial policy module."*

3. The main novelty of GCAM-China-v8 relative to earlier GCAM-China, GCAM-TU, CNCAP, GCAM-China-ABaCAS, and other China-focused GCAM variants remains insufficiently clear. I suggest adding a compact comparison table that explicitly summarizes differences in model version, base year, spatial resolution, sectoral coverage, technology detail, temporal structure, policy representation, openness, and typical applications.

**Author's response**: Thank you for this helpful suggestion. We have revised Table 1 in Section 2.2 to provide a compact comparison of representative China-focused GCAM-based models, coupled frameworks, and GCAM-China model-family developments. Section 2.3 Overview of GCAM-China further summaries the main updates of GCAM-China-v8.

***Revised text:***

***Section 2.2, the fourth paragraph:*** *"Overall, national-scale GCAM applications have enhanced sectoral or technology representations for China; GCAM+ frameworks have extended GCAM through coupling with air-quality, health, socioeconomic, or power-system models; and the GCAM-China model family has provided province-level representation of China within the core GCAM framework. Table 1 compares representative China-focused GCAM-based models and frameworks in terms of their GCAM version, calibration year, spatial resolution, sectoral and technological detail, temporal structure, model coupling, openness, policy representation, and typical applications."*

*Table 1 Representative China-focused GCAM-based models, coupled frameworks, and GCAM-China model-family developments*

<table>
<tr><th>Model/ Framework</th><th>Version</th><th>Base year</th><th>Spatial resolution</th><th>Sectoral coverage & technology detail</th><th>Temporal structure</th><th>Model coupling</th><th>Openness</th><th>Policy representation and typical applications</th></tr>
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</table>

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *technology dynamics(Pan et al., 2023, 2022)* |
| *GCAM-TU-Hydrogen* | *GCAM v7.0* | *2015* | | *$H_2$ production, transport, distribution, and end use; interregional $H_2$ trade* | | | | *$H_2$ supply and demand; technology adoption; international trade(Zhang et al., 2024)* |
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| *CNCAP* | *GCAM-China v4.3* | *2010; DPEC harmonized to 2015* | | *Emission-source technologies; fleet turnover; EOP controls* | | *GCAM-China + MEIC + DPEC* | *Used in published studies; method, selected inputs/scenarios/results available depending on study* | *Emission projections; climate–clean-air co-control; health assessment (Tong et al., 2020; Cheng et al., 2021, 2023)* |
| *GCAM-China-ABaCAS* | *GCAM-China; v4.3* | *2010; calibrated for 2010/2015* | | *Detailed emission sectors and technologies; localized emission factors; EOP controls* | | *GCAM-China + ABaCAS-EI + CMAQ* | | *Air-quality attainment; climate–clean-air co-benefits; health impacts (Xing et al., 2020; Dong et al., 2024; Sun et al., 2024)* |
| *GCAM-China-v6* | *GCAM-China v6* | *2015* | *Provincial (31 provinces)* | *Province-level energy-economic representation; building sector split by urban/rural households; national biomass market; provincial $CH_4$ and $N_2O$ emissions from resource and agriculture sectors; wind/PV represented without province-specific supply curves* | | | | *Provincial mitigation pathways; energy-system transitions; sectoral and regional policy analysis(Deng et al., 2025; Kim et al., 2024; Lou et al., 2025; Wang et al., 2025; Yin et al., 2026a; Yu et al., 2019, 2020)* |
| *GCAM-China-v7* | *GCAM-China v7* | *2015* | | *GCAM-Macro coupling added;*<br><br>*high-resolution provincial wind and PV supply curves;*<br><br>*building sector disaggregated by urban/rural households and income group; provincial biomass markets; provincial $CH_4$ and $N_2O$* | | *—* | *Fully open: code, inputs, scenarios, outputs* | *Provincial mitigation pathways; energy-system transitions; national policy analysis* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | *emissions from energy, resource, and agriculture sectors* | | | | |
| *GCAM-China-v8 (this study)* | *GCAM-China v8* | *2021* | | *Current documented release;*<br><br>*inherits earlier province-level GCAM-China capabilities; adds endogenous subnational water supply and demand; construction-vintage-specific coal-fired power technologies; province-level policy specification* | | | *Open-source release documented in this study; code, input data, scenarios, outputs, and documentation provided* | *Provincial mitigation pathways; energy-system transitions; sectoral and regional policy analysis;* |

***Notes:*** *EOP denotes end-of-pipe emission control; MEIC denotes the Multi-resolution Emission Inventory for China; DPEC denotes the Dynamic Projection model for Emissions in China; ABaCAS-EI denotes the ABaCAS emission inventory; CMAQ denotes the Community Multiscale Air Quality model; GCAM-China-v6 and GCAM-China-v7 are listed to indicate major capabilities established during earlier GCAM-China development. GCAM-China-v8 is the current open-source release documented in this study and consolidates inherited capabilities with additional updates.*

***Section 2.3 Overview of GCAM-China:*** *"Several model features documented in this study were originally developed in earlier GCAM-China versions, including provincial wind and solar PV resource supply curves, building-sector disaggregation by income, biomass markets, and energy-sector non-$CO_2$ emissions. GCAM-China-v8 builds on these prior developments by harmonizing the implementation with the core GCAM v8.2 framework and by updating, consolidating, and documenting key features in the open-source release. Major updates include updating the calibration year from 2015 to 2021, endogenizing subnational water supply and demand, disaggregation of coal-fired power generation technologies by construction vintage, and adding a provincial policy module."*

4. For water withdrawal and water consumption, the manuscript should explain the difference between the model base-year data and official statistics. For example, China's

2024 Water Resources Bulletin reports total national water use of approximately 600 billion $m^3$.

**Author's response**: We thank the reviewer for this important comment. We have clarified that GCAM-China-v8 base-year water withdrawal and consumption estimates may differ from official statistics and have added this issue as a limitation of the current model version. Accordingly, we revised the water-related results analysis in Section 3.3 to focus on the temporal changes, provincial patterns, and cross-scenario differences.

***Revised text:***

***Section 4 Discussion and conclusions, the fifth paragraph:*** *…"A further limitation is that GCAM-China-v8 inherits the globally harmonized water accounting framework of core GCAM v8.2, in which base-year water withdrawal and consumption are derived from globally consistent water-demand datasets and sectoral withdrawal/consumption coefficients (Joint Global Change Research Institute (JGCRI), 2026a), rather than being fully calibrated to official Chinese water statistics. Although China-specific information is used to parameterize provincial and sectoral water shares, modeled national water totals may therefore differ from official statistics." …*

***Section 3.3 Water:*** *"Water demand evolves differently for withdrawals and consumption over time (Fig.13). Total withdrawals follow a declining trend after mid-century, whereas total water consumption shows a more stable trajectory, varying within 210-235 $km^3$ over the projection period with only small differences between scenarios. Compared with REF, the CN mainly alters the sectoral composition of water demand rather than total levels.*

*Water withdrawals follow an inverted-U pattern in both scenarios, increasing by about 9% from 2021 to a peak around 2030-2040 before declining toward 2060. The decline is stronger under CN, where total withdrawals fall to about 14% below the peak level by 2060, compared with about 9% below the peak under REF. Irrigation remains the largest component, accounting for 35-40% of total withdrawals throughout. The post-peak decline is mainly driven by electricity generation, with withdrawals decreasing by roughly 25% by 2060. Manufacturing and municipal withdrawals increase by about 15% during the early projection periods and then stabilize, while livestock and primary energy remain below 7% of the national total withdrawals. Compared with REF, electricity-related withdrawals decline earlier and more strongly under CN, resulting in a difference of 23 $km^3$ in total withdrawals by 2060. In contrast, irrigation withdrawals remain similar across scenarios.*

*Water consumption follows a different pattern from water withdrawals. Total consumption increases by about 10% in the early projection period and then remains broadly stable through 2060, with cross-scenario differences of less than 2%. Irrigation remains the dominant component, accounting for 35-38% of total water consumption, followed by manufacturing and municipal consumption at 23% and 17%, respectively. Electricity generation contributes about*

*14-17% and remains relatively stable after mid-century, while livestock increases slightly from 17 to 20 km$^3$, and primary energy remains negligible. Differences between REF and CN are small, with total consumption differing by less than 2% in 2060.*

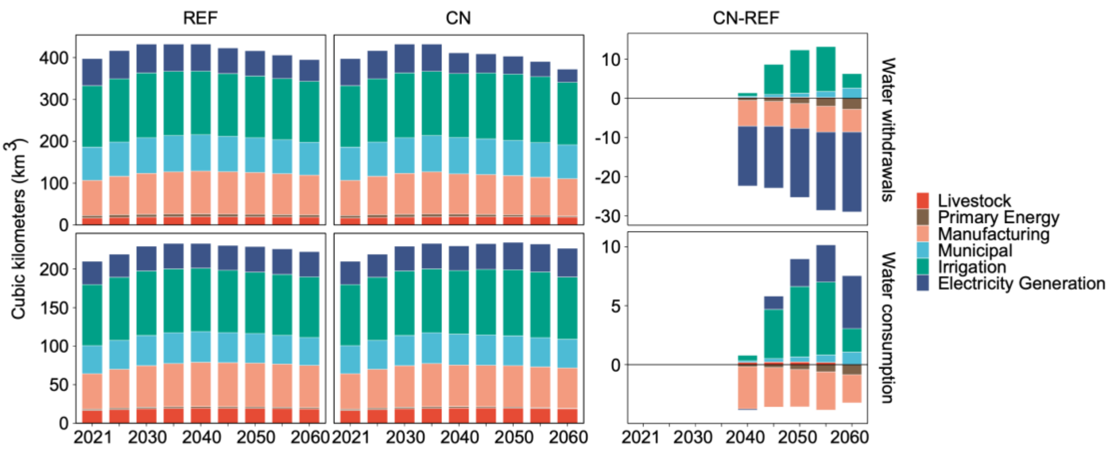


***Figure 13: Water withdrawals and consumption by sector under REF and CN scenarios.***

5. Please clarify whether the model explicitly represents mitigation technologies or control measures for non-$CO_2$ greenhouse gases. This is especially important for assessing China's 2035 NDC-related climate targets. The authors should explain how non-$CO_2$ mitigation contributions are quantified, and how they interact with $CO_2$ mitigation.

**Author's response**: Thank you for raising this point. We have revised the manuscript to clarify how non-$CO_2$ GHG mitigation is represented, how non-$CO_2$ mitigation contributions are quantified, and how non-CO2 mitigation interacts with $CO_2$ mitigation in GCAM-China-v8.

***Revised text:***

***Section 2.6.3 Non-$CO_2$ greenhouse gas emissions, the first paragraph****: "We extend GCAM-China-v8 to represent $CH_4$ and $N_2O$ emissions from energy end-use and related sectors at the provincial level. Non-$CO_2$ emissions from resource production and agriculture, including major methane sources such as coal mine methane and rice-cultivation methane, are retained following the core GCAM representation at the national or land-use-unit level, depending on the source category. Accordingly, emissions from these sources are reported at their corresponding spatial scales rather than being disaggregated to provinces in the current version." ...*

*"...Core GCAM represents non-$CO_2$ abatement through parameterized marginal abatement cost (MAC) curves that modify emission factors under GHG prices at the region and source-*

*category level. In GCAM-China-v8, we retain the core national/source-level non-$CO_2$ representation and inherited controls where implemented, but do not develop new source-specific and province-specific $CH_4$ and $N_2O$ MAC curves. Provincial $CH_4$ and $N_2O$ changes reflect activity-linked responses to changes in fuel use, service demand, sectoral output, technology deployment, and national/source-level emission-factor trajectories. In this study, non-$CO_2$ mitigation contributions are quantified using a scenario-difference approach. Specifically, we compare $CH_4$ and $N_2O$ emissions in the carbon-neutrality scenario with those in the reference scenario and report the difference in $CO_2$-equivalent terms using 100-year AR4 GWP values. $CO_2$ and non-$CO_2$ emissions interact through the common GHG policy framework in $CO_2$-equivalent terms, mainly because $CO_2$ mitigation reshapes the energy system and thereby affects activity-linked $CH_4$ and $N_2O$ emissions."*

***Section 3.2 Non-$CO_2$ greenhouse gas emissions, the first paragraph:*** *"We quantify non-$CO_2$ mitigation contributions as the difference between the REF and CN scenarios, expressed in CO2-equivalent terms using 100-year AR4 GWP values. Compared with REF, the CN scenario shows stronger reductions in both total national non- $CO_2$ greenhouse gas emissions and the province-resolved subset of non- $CO_2$ emissions from energy end-use and related sectors (Fig.12)."*

6. The calibration procedure should be described more systematically. Please state the calibration targets, benchmark datasets, calibration years, and sector-specific adjustment methods. It would be helpful to provide a table summarizing calibration by sector, including energy supply, electricity, industry, building, transport, water, and land.

**Author's response**: We have added a new section in the Supplementary Material to describe the calibration procedure of GCAM-China-v8 more systematically, together with a new summary table, Table SM8, which reports the calibration targets, benchmark datasets, calibration years, and sector-specific adjustment methods for major sectors, including energy supply, electricity, industry, buildings, transport, water, and land.

***Added section:***

***Supplementary Material, Calibration procedure:*** "*GCAM-China-v8 follows the core GCAM data-system approach for historical calibration, in which calibration parameters and shareweights are adjusted to reproduce benchmark activity levels and fuel, technology, or mode shares during the calibration years. For China's provincial end-use sectors, including industry, buildings, and transport, provincial energy balance data are used to derive historical final energy use by province, sector, and fuel. Model shareweights are then adjusted to reproduce observed historical fuel and technology shares within each provincial end-use sector, ensuring consistency between modeled provincial final energy structure and historical statistics. For sectors represented at other spatial scales in the core GCAM framework, such as water and* *land, China-region, basin-level, or land-use-region outputs are retained or harmonized with core GCAM representations and then allocated or mapped to provinces, basins, or grid cells using historical shares, spatial mapping files, or sector-specific allocation datasets. Water calibration focuses on parameterizing historical water-use coefficients and spatial allocation patterns. Sector-specific water demand coefficients are derived from historical water withdrawal and consumption statistics. Provincial water demands are then allocated to river basins based on historical spatial distributions. The Land-use calibration is performed at the GCAM land-use-region level because agricultural production and land allocation are represented at this spatial scale. Provincial results are obtained through spatial mapping rather than independent provincial calibration. Table SM8 summarizes the sector-specific calibration targets, benchmark datasets, calibration years, and adjustment methods.*"

*Table SM8 Sector-specific calibration targets, benchmark datasets, calibration years, and adjustment methods in GCAM-China-v8*

| ***Sector / module*** | ***Calibration target(s)*** | ***Benchmark dataset(s)*** | ***Calibration year(s)*** | ***Calibration / adjustment method*** |
|---|---|---|---|---|
| *Energy* | *Energy production and consumption by fuel and sector* | *Provincial energy balance data for China* | *1990-2021, 5-year steps* | *Adjust technology and fuel share weights to reproduce the same shares* |
| *Electricity* | *Electricity generation by technology/fuel* | *Provincial energy balance data for China; provincial electricity generation by fuel from the China Power Statistical Yearbook* | *1990-2021, 5-year steps* | *Adjust technology and fuel share weights to reproduce the same historical generation shares* |
| *Industry* | *Final energy use by technology/fuel* | *Provincial energy balance data for China; China Statistical Yearbook* | *1990-2021, 5-year steps* | *Adjust fuel and technology share weights to reproduce the same historical industrial energy-use shares* |
| *Buildings* | *Final energy use by technology/fuel* | *Provincial energy balance data for China; Historical per capita floorspace for urban and rural households* | *1990-2021, 5-year steps* | *Adjust fuel and technology share weights to reproduce the same historical building energy-use shares* |
| *Transport* | *Final energy use by fuel* | *Provincial energy balance data for China; transport activity indicators where available* | *1990-2021, 5-year steps* | *Adjust fuel and mode share weights to reproduce the same historical transport energy-use shares* |
| *Water* | *Water-use coefficients and spatial allocation patterns* | *Core GCAM water datasets; China Water Resources Bulletin* | *1990-2021, 5-year steps* | *Parameterize sectoral water demands using GCAM water-use* |

| | | | | |
|---|---|---|---|---|
| | | | | *coefficients and China-specific inputs; allocate and map demands using historical provincial and province–basin shares.* |
| *Land* | *Agricultural production and land allocation* | *Core GCAM land datasets; FAOSTAT* | *1990-2021, 5-year steps* | *Spatial mapping of agricultural production and land allocation* |

7. The REF and CN scenarios need a more quantitative description. Please provide a concise table summarizing key assumptions. This would help readers distinguish model assumptions from model results.

**Author's response**: We thank the reviewer for this helpful suggestion. We have added **Section 2.9 Scenario design** and a concise summary table 3 in the revised manuscript to clarify the key assumptions used in the REF and CN scenarios.

***Added section:***

***Section 2.9 Scenario design****: "We use scenario analysis to illustrate how GCAM-China-v8 represents responses to different socioeconomic, energy-system, and climate-policy assumptions. Given the focus of this paper on model structure, data development, and analytical capabilities, these scenarios are designed as illustrative model experiments based on explicitly defined assumptions.*

*We designed two main scenarios following the approach adopted in previous GCAM applications (Kaufman et al., 2020). The Reference scenario (REF) assumes population and GDP growth consistent with the SSP2 "middle-of-the-road" storyline and imposes no additional climate-policy constraints to achieve specific emissions targets. The Carbon neutrality scenario (CN) adopts the same socioeconomic assumptions as REF but imposes an additional climate constraint consistent with China's carbon-neutrality target. Specifically, energy-system $CO_2$ emissions decline linearly from 2040 to approximately net zero by 2060. Table 3 summarizes the key assumptions of the two main scenarios, and the model-period $CO_2$ constraint values are reported in Supplementary Table SM7."*

***Table 3 Scenario design***

| ***Scenario*** | ***Socioeconomic drivers*** | ***Climate policy constraints*** |
|---|---|---|

| | | |
|---|---|---|
| *Reference (REF)* | *Default (SSP2)* | *Default (No explicit policy)* |
| *Carbon neutrality (CN)* | *Default (SSP2)* | *China carbon-neutrality constraint. $CO_2$ emissions decline linearly from 2040 (7812 Mt) to net zero by 2060* |

***Table SM7: $CO_2$ emissions constraint in the CN scenario***

| ***Year*** | ***Energy-system $CO_2$ constraint in CN scenario*** |
|---|---|
| *2040* | *7812 Mt $CO_2$* |
| *2045* | *5859 Mt $CO_2$* |
| *2050* | *3906 Mt $CO_2$* |
| *2055* | *1953 Mt $CO_2$* |
| *2060* | *0 Mt $CO_2$* |

8. The simplified representation of inter-provincial electricity trade requires stronger justification. Please clarify whether transmission capacity, congestion, losses, and grid topology are ignored, approximated, or implicitly represented. In addition, please explain whether the model explicitly excludes electricity transmission between provinces that are not geographically adjacent and are not connected by ultra-high-voltage transmission lines.

**Author's response**: Thank you for this important comment. Consistent with core GCAM and GCAM-USA implementations, electricity trade in GCAM-China-v8 is represented as aggregate market-mediated exchange rather than physical power flows over an explicit transmission network. In this representation, transmission capacity, congestion, grid topology, and province-pair-specific connectivity are not explicitly resolved. Electricity losses are represented only as aggregate own-use and transmission-and-distribution demand in provincial electricity accounting, not as route- or distance-specific losses.

***Revised text:***

**Clarification of the simplified representation of electricity trade**

***Section 2.5.2 (2) Electricity trade:*** "*GCAM-China-v8 represents electricity trade as an aggregated market structure, not as a physical transmission-network model. The electricity-market structure includes intra-grid provincial competition and inter-grid gross trade, following the general approach used in GCAM-USA (Chini et al., 2018). Intra-grid electricity exchange implicitly through market competition. Across China's six electricity grid regions, electricity exchange is represented using an aggregate gross-trade formulation. Historical inter-provincial electricity-flow data from the Compilation of Statistical Data of Electric Power Industry (China Electricity Council, 2005) are mapped to the six grid regions and aggregated* *after excluding flows within the same grid region. The inter-grid flows are used to calibrate base-year gross import and export shares. For each grid region r, base-year net electricity exports are calculated as equation (1):*

$$Net\,Trade_{r,t} = Generation_{r,t} + Cogeneration_{r,t} - Ownuse_{r,t} - Consumption_{r,t} \quad (1)$$

*Where* $Generation_{r,t}$, $Cogeneration_{r,t}$, $Ownuse_{r,t}$, *and* $Consumption_{r,t}$ *denote grid-region electricity generation, industrial cogeneration output, net power-sector own use, and a combination of all electricity demand, respectively. Positive values of* $Net\,Trade_{r,t}$ *indicate net exports, whereas negative values indicate net imports.*

*In future periods, electricity exchange is represented as stylized aggregate trade among the six grid regions, with fixed trade shareweights carrying forward base-year trade participation. The model does not impose explicit transmission-capacity constraints or resolve bilateral transmission links, grid topology, congestion, individual ultra-high-voltage corridors, or route-specific transmission losses. Average delivery losses are represented separately through provincial electricity transmission and distribution sectors. Modeled electricity trade should therefore be interpreted as aggregate inter-grid exchange rather than physical power-flow or transmission-expansion projections.*"

**Acknowledgement of our limitation:**

***Section 4 Discussion and conclusion, the fourth paragraph:*** *"Consistent with the core GCAM and GCAM-USA implementations, GCAM-China-v8 represents inter-provincial electricity trade as aggregate market-mediated exchange rather than physical power flows over an explicit transmission network. This simplification supports long-term, cross-sectoral scenario analysis but does not resolve grid topology, transmission-capacity constraints, or congestion effects that may shape renewable integration and inter-provincial electricity sharing (Jenkins et al., 2022). The projected electricity trade should be interpreted as long-term aggregate exchange under the assumed market structure, rather than physically feasible flows through specific transmission corridors. Future work could address this limitation by developing China-specific representations of inter-provincial transmission."*

9. The nuclear incentive policy example appears somewhat arbitrary in the current manuscript. The authors should either justify the policy design more clearly, including its empirical or policy basis, or move it to the SI as a methodological demonstration rather than presenting it as a central scenario result.

**Author's response:** We thank the reviewer for this helpful comment. We have revised the manuscript to highlight this example as a demonstration of GCAM-China-v8's province-level policy-specification capability. The revised text clarifies that this module shows how a national technology-policy target can be translated into province-level model inputs and how such province-level specifications can affect simulated energy-transition pathways.

***Revised text:***

***Section 2.8 Province-level policy specification: an illustrative nuclear power example, the first paragraph:*** *"Existing IAMs and related scenario analyses typically represent policy interventions through carbon pricing (Huang et al., 2023), emissions constraints (Fuhrman et al., 2023), and technology-cost assumptions, but sector-specific policies remain insufficiently represented, especially at subnational scales. This limitation is particularly relevant in the Chinese context, where many energy and climate policies are formulated at the national level but implemented through province-specific planning, infrastructure deployment, and technology choices. GCAM-China-v8 addresses this need by enabling province-level policy specification. In this section, we use nuclear power as an illustrative example to demonstrate how a national technology-policy target can be translated into province-level model inputs and how such province-level specifications can be used to explore subnational energy-transition pathways.*

***Section 2.8, last paragraph:*** *"As a hypothetical example intended as a methodological demonstration, we implement policy interventions that promote nuclear electricity generation. Nuclear power is selected because its development is supported by explicit national capacity targets and is concentrated in several major coastal provinces." "…These scalars are used to illustrate how national policy targets can be translated into province-level model inputs."*

10. Please check the citation to "China Industrial Statistical Yearbook (2026)." This appears likely to be erroneous unless the 2026 edition is already available and intentionally used. If not, the citation should be corrected to the appropriate name (for example China Industrial Statistical Yearbook 2025 (2026)).

**Author's response:** Thank you for this clarification. We have corrected the citation from "China Industrial Statistical Yearbook (2026)" to "China Industrial Statistical Yearbook 2025 (2026)" in both the main text and the reference list.

***Revised text:***

***Section 2.5.2 Industry, the second paragraph:*** *"For iron and steel and coking sectors, demands are expressed as physical production quantities (million tons) derived from provincial-level statistics published in the China Industrial Statistical Yearbook 2025 (2026) by the National Bureau of Statistics of China (NBSC)."*

11. Please ensure consistent terminology for water withdrawal, water consumption, water demand, and water use throughout the manuscript and supplementary materials.

**Author's response:** We thank the reviewer for highlighting the need for consistent terminology. We have revised section 2.7 and section 3.3 in the manuscript accordingly. In the revised text, **water demand** is used as the general term for sectoral requirements, replacing broader or less specific expression of water use. And it is tracked endogenously across all sectors in terms of both water withdrawal and consumption. For quantitative water accounting, we explicitly distinguish between water withdrawal and water consumption. **Water withdrawal** refers to the total volume of water extracted from the supply system, while **water consumption** represents the fraction not returned for immediate reuse.

***Revised text:***

***Section 2.7:*** *"GCAM-China-v8 represents water supply and demand endogenously at the subnational scale. Water resource availability and sectoral demands are resolved through a water market mechanism (Joint Global Change Research Institute (JGCRI), 2026b), in which water prices increase as demand approaches resource limits.*

*Water supply is represented from three freshwater sources: renewable water (surface and ground), non-renewable (fossil) groundwater, and desalinated water. Seawater is treated as an unlimited resource for cooling thermal power plants in coastal provinces. All water resources are characterized at the HUC-2 river basin level, with source-specific extraction costs and availability constraints. China's water system is represented by 22 river basins (Supplementary Table SM4), some of which are shared with neighbouring regions, such as Mongolia, Russia, and India. Detailed descriptions of the GCAM water supply and market mechanisms can be found in Kim et al. (2016) and Turner et al. (2019).*

*Water demand is tracked endogenously across all sectors in terms of both water withdrawal and consumption. Withdrawal refers to the total volume of water extracted from the supply system, while consumption represents the fraction not returned for immediate reuse. Water demand drivers (activities) are modelled at multiple spatial scales and mapped to the province level.*

*Several sectors, including electricity generation, manufacturing, and municipal water demand, are represented directly at the provincial level. For municipal water demand, province-specific water demand coefficients are calculated using historical water withdrawal data from China's Water Resources Bulletin (Ministry of Water Resources of the People's Republic of China, 2021). Municipal demand is driven by provincial socioeconomic trends, while the withdrawal-to-consumption ratio is assumed to improve at a constant rate over time across provinces.*

*Manufacturing water demand coefficients for specific sectors (iron and steel, cement, chemicals, and coke) are derived from industrial water-use quotas issued by the Ministry of Water*

*Resources of China and further calibrated using historical province-level manufacturing water demand data (Ministry of Water Resources of the People's Republic of China, 2021). These coefficients are held constant over time, so future industrial water demand depends on projected activity levels.*

*For the power sector, water withdrawal and consumption coefficients are specified by fuel, generation technology, and cooling system based on Macknick et al. (2012). These coefficients are combined with province-level cooling technology shares derived from a national power plant database to estimate average water-use coefficients by technology and fuel. The resulting coefficients are calibrated using historical thermal power water demand data from Zhou et al. (2020).*

*Three additional sectors, primary energy extraction (mining), agriculture (irrigation), and livestock, are not represented at the province level. Their water demands are driven by national activity (energy and livestock) or land-use regions (irrigation). Water demand coefficients for these sectors are calibrated using historical total water demand data from China's Water Resources Bulletin (Zhou et al., 2020), following Calvin et al. (2019) and Graham et al. (2021). These demands are then downscaled to provinces using sector-specific historical demand shares derived from 0.5° × 0.5° gridded water demand data (Huang et al., 2018).*

*Province-level water demands are aggregated to the river basin level, where water supply and demand are balanced. Province-to-basin mappings (Supplementary Table SM4) follow Huang et al. (2018) and are fixed at 2010 values, so future inter-basin competition reflects historical spatial demand patterns.*"

***Section 3.3***: "*Water demand evolves differently for withdrawals and consumption over time (Fig.13). Total withdrawals follow a declining trend after mid-century, whereas total water consumption shows a more stable trajectory, varying within 210-235 km$^3$ over the projection period with only small differences between scenarios. Compared with REF, the CN mainly alters the sectoral composition of water demand rather than total levels.*

*Water withdrawals follow an inverted-U pattern in both scenarios, increasing by about 9% from 2021 to a peak around 2030-2040 before declining toward 2060. The decline is stronger under CN, where total withdrawals fall to about 14% below the peak level by 2060, compared with about 9% below the peak under REF. Irrigation remains the largest component, accounting for 35-40% of total withdrawals throughout. The post-peak decline is mainly driven by electricity generation, with withdrawals decreasing by roughly 25% by 2060. Manufacturing and municipal withdrawals increase by about 15% during the early projection periods and then stabilize, while livestock and primary energy remain below 7% of the national total withdrawals. Compared with REF, electricity-related withdrawals decline earlier and more strongly under*

*CN, resulting in a difference of 23 km$^3$ in total withdrawals by 2060. In contrast, irrigation withdrawals remain similar across scenarios.*

*Water consumption follows a different pattern from water withdrawals. Total consumption increases by about 10% in the early projection period and then remains broadly stable through 2060, with cross-scenario differences of less than 2%. Irrigation remains the dominant component, accounting for 35-38% of total water consumption, followed by manufacturing and municipal consumption at 23% and 17%, respectively. Electricity generation contributes about 14-17% and remains relatively stable after mid-century, while livestock increases slightly from 17 to 20 km$^3$, and primary energy remains negligible. Differences between REF and CN are small, with total consumption differing by less than 2% in 2060*."

Overall, the manuscript documents an important model development effort, but its contribution would be clearer if the authors more explicitly positioned GCAM-China-v8 relative to previous China-focused GCAM models and strengthened the documentation of calibration, scenario assumptions, water accounting, electricity trade, and non-$CO_2$ mitigation.