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 #2

General comments:

This paper presents GCAM-China-v8, an open-source integrated assessment model (IAM) that disaggregates China into 31 province-level regions within a globally consistent framework. By bridging the gap between global climate targets and local implementation, this model serves as a tool for analyzing subnational energy and emission pathways. National-scale IAMs are essential because climate policies are increasingly implemented at the subnational level. GCAM-China-v8 provides the necessary resolution to investigate not just if China can reach carbon neutrality, but where and how these transitions will physically and socioeconomically occur across its provinces.

The authors should be commended for the massive data-gathering and harmonization effort required to calibrate a 31-province model to a base year as recent as 2021. Unlike many previous China-focused models that were project-specific or poorly documented, GCAM-China-v8 is a community-shared framework, significantly enhancing the reproducibility and extensibility of China's climate research. A major technical advance is the explicit disaggregation of coal power by construction vintage. This allows the model to simulate realistic, staggered retirement pathways based on the actual age structure of provincial fleets rather than assuming a uniform national phase-out. The model disaggregates residential building demand into 20 consumer groups based on income deciles and urban-rural status. This enables vital research into energy equity and how technology adoption is driven by income heterogeneity. Reconstructing provincial supply curves for wind and solar using 10 km × 10 km grid-cell data ensures that the model reflects the physical and economic limits of renewable expansion more accurately than previous versions.

However, there are several limitations on the methodological choices and room for model improvements. The paper is worth considering for the publication if the following specific comments are addressed.

Author's response:

We thank the reviewer for the constructive and insightful comments. In response, we have revised the manuscript and Supplementary Information to improve methodological clarity, strengthen validation against historical provincial data, and more clearly define the model's scope and limitations.

Specific comments:

While the paper represents a significant step forward, several architectural choices and omissions require further clarification or more rigorous critical analysis.

1. **Socioeconomic projections**: The future population and GDP growth at the provincial level follow the SSP growth rates. This ignores the region-specific growth patterns, internal migrations and economic activities. This is critical for the future socioeconomic dynamics across the provinces. Further, the GDP values are used to project the sectoral demands. This typically provides the model with a downscaled nature rather than capturing the provincial level nuances, which further limits the reliability of the results on a provincial scale.

Author's response:

We thank the reviewer for this important comment. We revised Section 2.4 to clarify that provincial population and GDP pathways in GCAM-China-v8 are exogenous inputs constructed from historical provincial baselines and harmonized with SSP-consistent national assumptions. It preserves observed base-year provincial heterogeneity, but does not endogenously represent internal migration, province-specific demographic transitions, or locally differentiated economic restructuring; this limitation is now acknowledged. We also clarify that provincial sectoral demands are not obtained by simple GDP- or population-based downscaling. They are estimated through GCAM's calibrated demand framework. Provincial production shares are initialized from historical levels and can evolve with province-specific production costs, preserving base-year heterogeneity.

Revised Text:

Section 2.4 Socioeconomics, the first paragraph: *"GCAM-China-v8 uses exogenous province-level population and GDP trajectories as socioeconomic drivers, consistent with GCAM's core design. The trajectories are calibrated to historical provincial population, GDP, and GDP per capita patterns and harmonized with China-level SSP-consistent pathways to maintain consistency with the global GCAM framework. The base assumption follows the "middle-of-the-road" Shared Socioeconomic Pathway 2 (SSP2) (O'Neill et al., 2014), consistent with other 31 global regions in GCAM. Accordingly, the model does not endogenously represent internal migration, province-specific demographic transitions, or locally driven economic restructuring. In addition, Sectoral energy-service demands are driven by GDP and population but are not simple proportional projections. They are estimated through GCAM's service-demand functions,* *which include income and price responses, sector-specific elasticities, and provincial base-year activity levels. Provincial production shares are calibrated to historical provincial production levels and can evolve with province-specific production costs and technology competition, thereby preserving base-year heterogeneity while allowing future provincial patterns to respond to changing cost conditions."*

2. **Ambiguity in international transport**: While the main text mentions "international freight shipping" as one of four final transport demands, it is not explicitly clear how these emissions and energy demands are treated or allocated. The supplementary information indicates that "freight aircrafts" are excluded contradicting the main text. Such information needs to be made explicit and clear in the main text.

Author's response: Thanks for your careful review. We have clarified that, following the core GCAM and GCAM-USA approaches, international freight shipping energy demand is allocated to provinces based on provincial fuel-oil consumption, and the associated CO_2 emissions are calculated endogenously using fuel-specific emission factors in the GCAM-China-v8. We also clarify that "international freight shipping" refers exclusively to maritime freight transport and does not include freight aircraft.

Revised text:

Section 2.5.4 Transportation, the first paragraph: *"This sector is organized into four final demands: passenger travel, freight, long-distance passenger air, and international freight shipping, where international freight shipping refers exclusively to maritime freight transport and freight aircraft are not represented in the current version."*

Section 2.5.4 Transportation, the second paragraph*: "Mode competition at the subsector level accounts for the value of travel time, as reflected in the generalized cost Eq. (6).*

$$P_{m,p,t} = \frac{W_{p,t} \times \delta_{m,p,t}}{v_{m,p,t}} + \sum_j \left(S_{j,m,p,t} \times P_{j,m,p,t}\right) \quad (6)$$

Where W *is the wage rate ($/hour) calculated from the per capita GDP,* V *is a unitless parameter representing the cost associated with travel expressed as a multiplier of the wage rate (value of time, or VOT).* δ *is a dimensionless value-of-time parameter that expresses travel-time costs as a multiplier of the wage rate.* v *is the average door-to-door speed of mode* m *(KM/hour).* $S_{j,m,p,t}$ *and* $P_{j,m,p,t}$ *is the share and cost of technology j in mode* m*, province* p*, and year* t*. Technology costs are calculated using Eq. (7).*

$$P_{j,m,p,t} = \frac{P_{f,p,t} \times EI_{j,m,p,t} + NP_{j,m,p,t}}{L_{j,m,p,t}} \quad (7)$$

Where $P_{f,p,t}$ is the fuel price, EI is the vehicle energy or fuel intensity, NP is the non-fuel price, and L is the load factor defined either as passengers per vehicle or tonnes per vehicle. Consistent with the implementation convention in core GCAM and GCAM-USA, historical national transport energy use is downscaled to provinces using provincial shares of the corresponding transport fuels reported in National Bureau of Statistics energy statistics. Long-distance passenger air and international freight shipping are allocated based on provincial shares of kerosene and fuel-oil consumption, respectively, while historical walking and cycling service demand is distributed in proportion to provincial population. Fossil-fuel CO_2 emissions are estimated endogenously from provincial fossil fuel consumption using fuel-specific emission factors."

3. **Temporal resolution vs. high-VRE findings**: The model predicts a Carbon Neutrality scenario where wind and solar reach 75% of total generation by 2060. However, the power sector still operates on an annual balance. This methodological choice is a major limitation: it cannot capture the diurnal and seasonal variability of renewables or the physical feasibility of the storage and grid flexibility required to support such a mix.

Author's response: We thank the reviewer for raising this important limitation. Consistent with the scope of most IAMs, GCAM-China-v8 is designed to assess long-term, economy-wide, cross-sectoral transition pathways, rather than to resolve detailed power-system operations. Accordingly, its annual-balance representation of the power sector cannot capture the diurnal and seasonal variability of wind and solar generation, nor can it verify the operational feasibility of the storage, transmission, and grid-flexibility requirements needed to support very high VRE shares. Assessing such operational feasibility generally relies on coupling IAMs with higher-temporal-resolution power-system models(Yin et al., 2026b). We have clarified this limitation in the discussion section.

Revised text:

Section 4 Discussion and conclusions, the fourth paragraph: *"As with most IAMs, GCAM-China-v8 is designed to assess long-term, economy-wide, cross-sectoral transition pathways rather than detailed power-system operations. This modeling scope is consistent with the broader methodological role of IAMs, which evaluate long-term structural transitions across sectors and regions rather than resolve sub-annual dispatch, transmission congestion, or grid stability constraints (Ou et al., 2021c). Such operational questions are typically examined by coupling IAMs with dedicated power-system planning or dispatch models (Yin et al., 2026b). Therefore, high wind and solar deployment should be interpreted as a long-term generation-mix outcome, not as an operationally validated power-system design."*

4. **Top-down reconciliation risks**: The authors apply "province- and sector-specific scaling factors" when bottom-up facility data exceeds IEA national totals. The magnitude of these scaling factors is not disclosed. This is a critical omission; if the adjustments are large, the top-down national constraints may be masking the very "regional heterogeneity" the model claims to capture.

Author's response: Thank you for raising this important concern. We clarified that all provinces are adjusted using the same scaling factor within each subsector-fuel category, so the reconciliation changes absolute energy-consumption levels but preserves provincial shares and spatial heterogeneity. We also corrected the original wording that could have implied province-specific scaling factors. To improve transparency, we added Table SM9 in the Supplementary Material, showing an illustrative subsector-fuel example with the original MEIC-HR provincial values, the scaling factor, reconciled values, and provincial shares before and after reconciliation. In addition, the validation results in Section 3.5 also show that, when national totals are well aligned with statistical benchmarks, GCAM-China-v8 reproduces historical provincial-level patterns in CO_2 emissions and key energy-system variables reasonably well. This provides additional evidence that the reconciliation procedure preserves the main spatial patterns represented in the bottom-up provincial inventory.

Revised Text:

Section 2.5.2 Industry, the first paragraph: *"To maintain international consistency, sectoral total energy consumption is reconciled with IEA Energy Balances when MEIC-HR facility-level data inconsistent with IEA sectoral totals. For each sector, a scaling factor calculated at the national level is applied uniformly to all provinces, thereby preserving their relative energy-consumption shares and the provincial heterogeneity represented in MEIC-HR. Tabel SM8 shows an illustrative subsector-fuel example with the original MEIC-HR provincial values, the scaling factor, reconciled values, and provincial shares before and after reconciliation."*

Supplementary Material, Table SM9:

Table SM9. Provincial energy-consumption shares before and after national-level reconciliation

Province	***Supply sector***	***Energy input***	***Scale factor***	***MEIC-HR bottom-up amount (EJ)***	***Percentage in total before***	***Reconciled amount (EJ)***	***Percentage in total after***
AH	*chemical energy use*	*elect_td_ind*	*1.6*	*0.007*	*2.71%*	*0.012*	*2.71%*
BJ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.002*	*0.72%*	*0.003*	*0.72%*
CQ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.006*	*2.08%*	*0.009*	*2.08%*
FJ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.004*	*1.56%*	*0.007*	*1.56%*

GD	*chemical energy use*	*elect_td_ind*	*1.6*	*0.007*	*2.50%*	*0.011*	*2.50%*
GS	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
GX	*chemical energy use*	*elect_td_ind*	*1.6*	*0.004*	*1.40%*	*0.006*	*1.40%*
GZ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.005*	*1.73%*	*0.008*	*1.73%*
HA	*chemical energy use*	*elect_td_ind*	*1.6*	*0.016*	*5.89%*	*0.026*	*5.89%*
HB	*chemical energy use*	*elect_td_ind*	*1.6*	*0.005*	*1.85%*	*0.008*	*1.85%*
HE	*chemical energy use*	*elect_td_ind*	*1.6*	*0.035*	*12.56%*	*0.055*	*12.56%*
HI	*chemical energy use*	*elect_td_ind*	*1.6*	*0.004*	*1.30%*	*0.006*	*1.30%*
HL	*chemical energy use*	*elect_td_ind*	*1.6*	*0.007*	*2.60%*	*0.011*	*2.60%*
HN	*chemical energy use*	*elect_td_ind*	*1.6*	*0.003*	*1.06%*	*0.005*	*1.06%*
JL	*chemical energy use*	*elect_td_ind*	*1.6*	*0.004*	*1.41%*	*0.006*	*1.41%*
JS	*chemical energy use*	*elect_td_ind*	*1.6*	*0.020*	*7.27%*	*0.032*	*7.27%*
JX	*chemical energy use*	*elect_td_ind*	*1.6*	*0.004*	*1.60%*	*0.007*	*1.60%*
LN	*chemical energy use*	*elect_td_ind*	*1.6*	*0.016*	*5.86%*	*0.026*	*5.86%*
NM	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
NX	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
QH	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
SC	*chemical energy use*	*elect_td_ind*	*1.6*	*0.003*	*1.14%*	*0.005*	*1.14%*
SD	*chemical energy use*	*elect_td_ind*	*1.6*	*0.044*	*15.84%*	*0.070*	*15.84%*
SH	*chemical energy use*	*elect_td_ind*	*1.6*	*0.011*	*3.91%*	*0.017*	*3.91%*
SN	*chemical energy use*	*elect_td_ind*	*1.6*	*0.011*	*4.16%*	*0.018*	*4.16%*
SX	*chemical energy use*	*elect_td_ind*	*1.6*	*0.046*	*16.72%*	*0.074*	*16.72%*
TJ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.005*	*1.84%*	*0.008*	*1.84%*
XJ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
XZ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.000*	*0.00%*	*0.000*	*0.00%*
YN	*chemical energy use*	*elect_td_ind*	*1.6*	*0.001*	*0.31%*	*0.001*	*0.31%*
ZJ	*chemical energy use*	*elect_td_ind*	*1.6*	*0.006*	*1.99%*	*0.009*	*1.99%*

Note: The same scaling factor (1.6) is applied uniformly to all provinces within the selected subsector–fuel category. The reconciled amounts are therefore proportional to the original MEIC-HR bottom-up amounts, and provincial shares remain unchanged except for rounding.

Section 3.5 Comparison to historical data

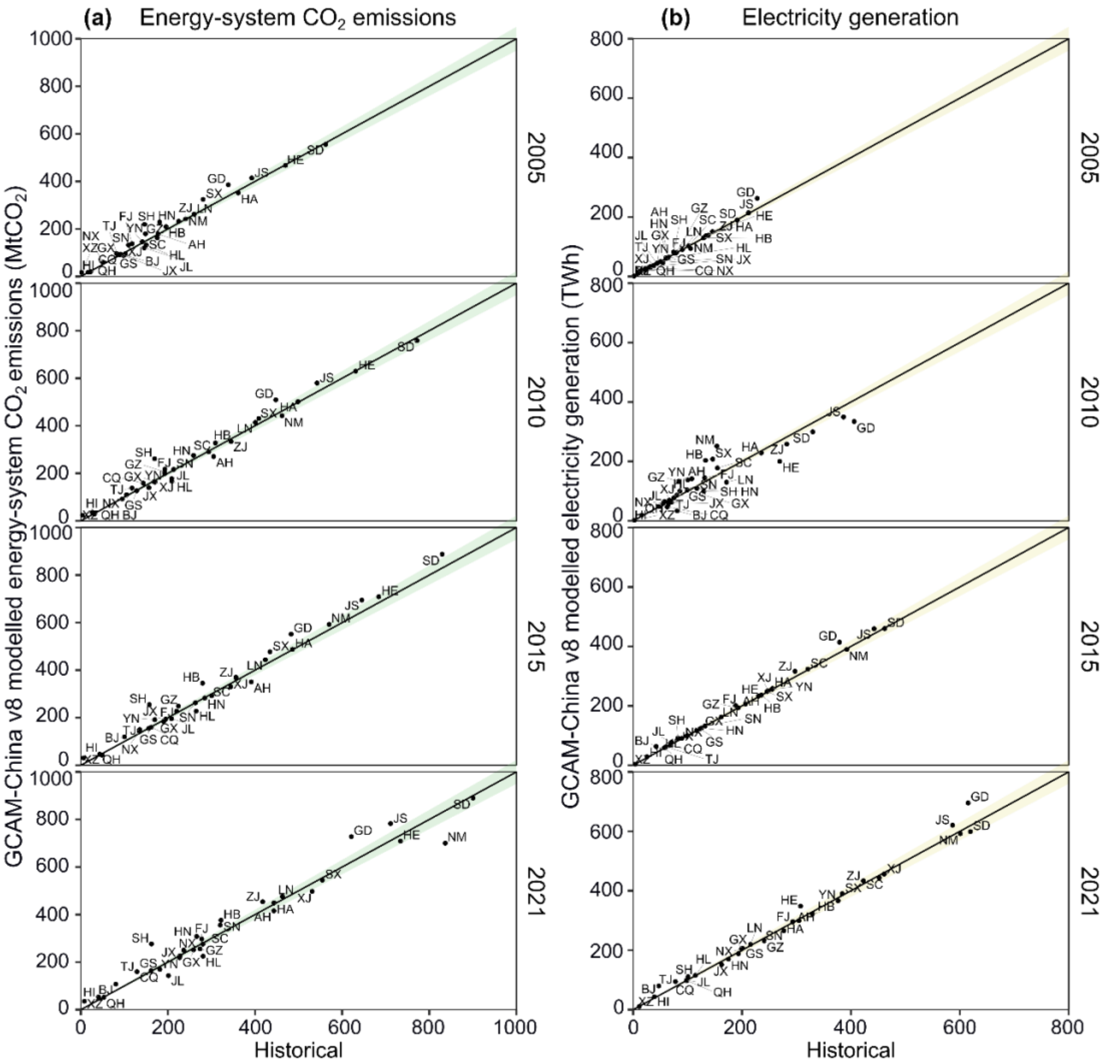

Figure 15: GCAM-China-v8 results versus historical inventory data.

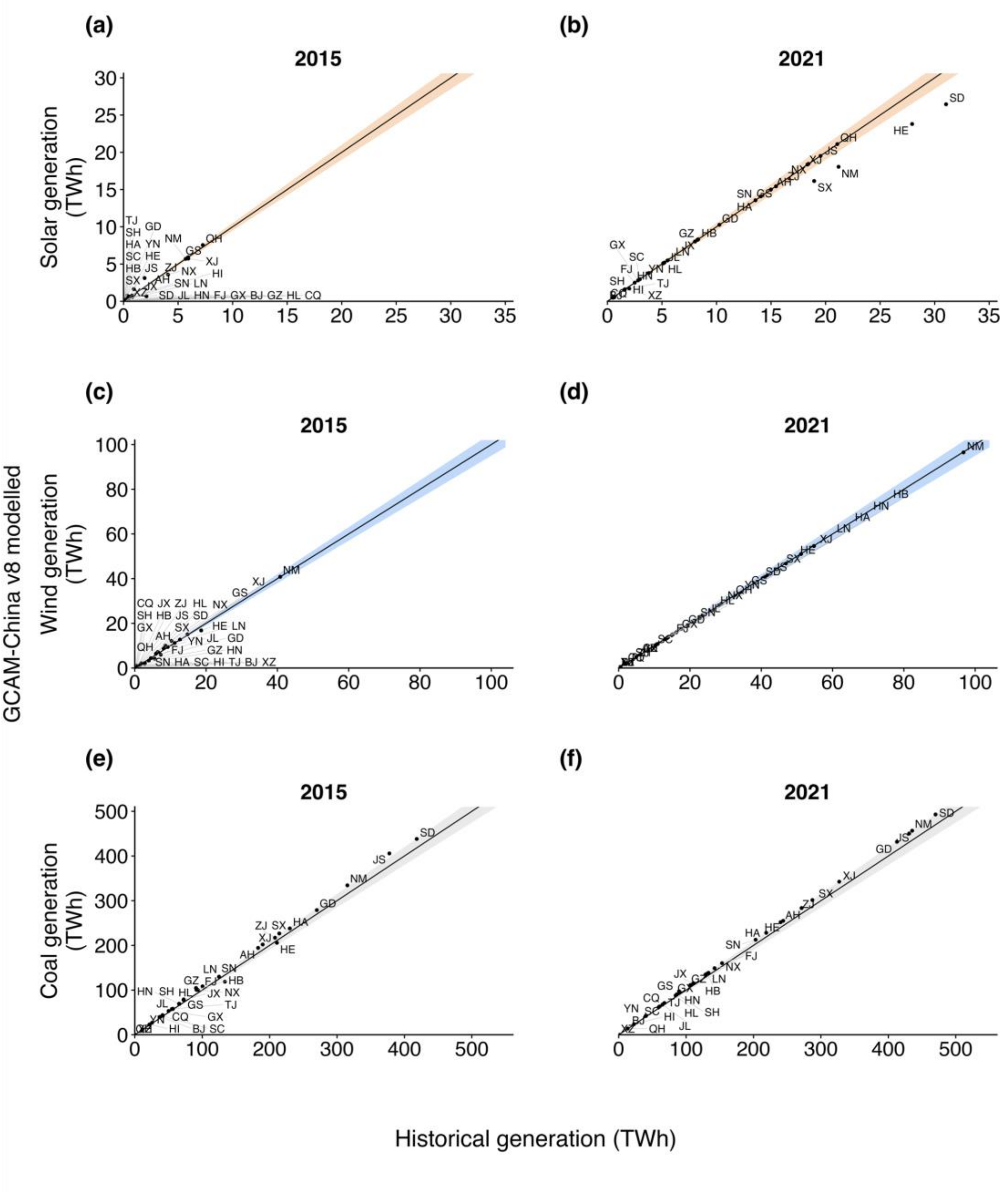

Figure 16. Comparison of GCAM-China-v8 modelled and historical provincial electricity generation by technology in 2015 and 2021.

Supplementary Material, Section Evaluation of GCAM-China-v8 scenario projections against recent trends and developments:

"To assess the consistency of GCAM-China-v8 scenario projections with recent trends and developments, we introduced a supplementary "Current policy"-NetZero scenario to characterize technology deployment and emissions-reduction trajectories under explicitly specified policy and emissions constraints and compared selected model outputs with historical statistics. This scenario provides a policy- and emissions-constrained pathway for evaluating how GCAM-China-v8 represents technology deployment and emissions reductions under current policy assumptions and China's long-term carbon-neutrality target.

The "Current policy"-NetZero scenario follows the design of Wang et al. (2026). It applies the Current-BAU policy pathway, which incorporates national policies adopted through 2025 and extrapolates these measures to 2030. No further strengthening of policies is assumed after 2030. Starting from 2040, a binding linear CO_2 decline constraint is imposed, reaching carbon neutrality by 2060.

We benchmarked selected model outputs against historical data and external statistical estimates for China's CO_2 emissions, electricity-generation mix, and BEV deployment (Figure SM1). The comparison shows that national CO_2 emissions in the "Current policy"-NetZero scenario are close to recent estimates from GCP and EDGAR over the overlapping years. The modeled generation shares of nuclear, solar, and wind power also broadly align with historical values in the overlapping period and increase thereafter under the combined effects of current policy assumptions and the long-term CO_2 decline constraint. For BEVs, the comparison is based on the BEV share in the LDV stock rather than the new-sales share. Historical data show a gradual increase in the BEV stock share during 2021-2025, and the "Current policy"-NetZero scenario projects continued expansion after 2025, indicating that GCAM-China-v8 represents the progressive electrification of the LDV stock. Because vehicle stock turnover is gradual, the BEV stock share naturally lags the more rapidly changing new-sales share."

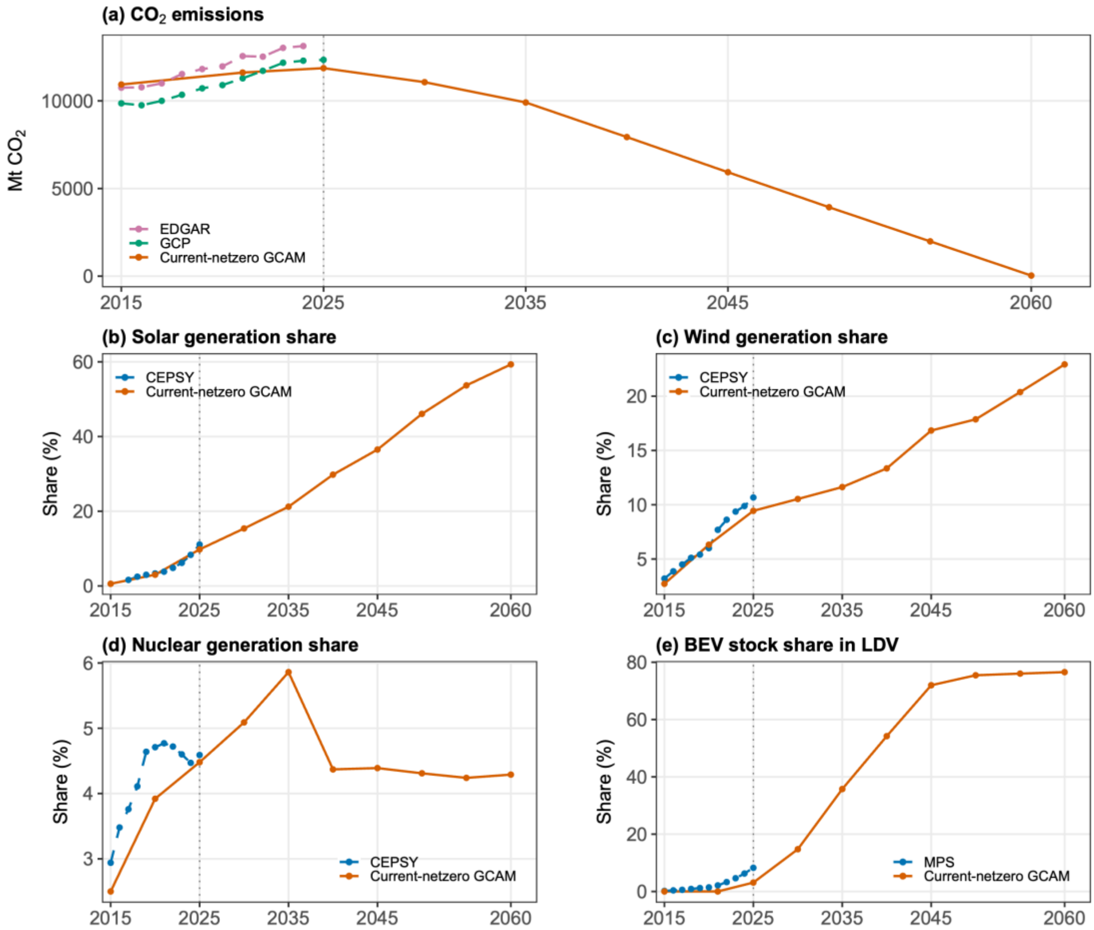

Figure SM1. Comparison of GCAM-China-v8 "Current policy"-NetZero scenario results with historical and external estimates for selected indicators in China.

Notes: Panels show (a) CO_2 emissions, (b) solar generation share, (c) wind generation share, (d) nuclear generation share, and (e) BEV stock share in the LDV fleet. Solid lines indicate GCAM-China-v8 "Current policy"-NetZero scenario results, while dashed lines indicate historical statistics or external estimates. The "Current policy"-NetZero scenario represents a pathway in which near-term socioeconomic, energy, and technology assumptions follow current-policy settings through 2025, with a carbon-neutrality constraint introduced from 2040 onward to achieve net-zero CO_2 emissions by 2060. CO_2 emissions are compared with estimates from the Global Carbon Project (GCP; Andrew and Peters, 2025) and the Emissions Database for Global Atmospheric Research (EDGAR; European Commission. Joint Research Centre., 2025). Solar, wind, and nuclear generation shares are calculated from national power generation statistics reported in China Electric Power Statistical Yearbook (China Electricity Council, 2025) and Statistical Communiqué of the People's Republic of China on the National Economic and Social Development (National Bureau of Statistics of China, 2025). BEV stock shares are calculated from vehicle stock statistics released by the Ministry of Public Security of the People's Republic of China (MPS; 2025). The vertical dotted line marks 2025. The "Current policy"-NetZero scenario outputs are available through the accompanying Zenodo repository at https://doi.org/10.5281/zenodo.21981604.

5. Simplistic trade and transmission: Electricity trade is modeled using empirical ratios rather than physical grid topology or transmission constraints. Since grid bottlenecks are a primary driver of provincial energy decisions in China, this simplification may lead to overly optimistic projections of inter-provincial energy sharing.

Author's response: We thank the reviewer for raising this important concern. We agree that grid bottlenecks and transmission constraints are important drivers of provincial energy decisions in China. Consistent with core GCAM and GCAM-USA implementations, GCAM-China-v8 represents electricity trade as aggregate market-mediated exchange rather than physical power flows over an explicit transmission network. This simplified representation supports the main purpose of GCAM-China-v8, which is long-term, multi-sector, province-level scenario analysis, but it cannot replace detailed power-system planning or dispatch models. We therefore clarified in the revised manuscript that electricity trade results should be interpreted as long-term aggregate exchange patterns under the assumed market structure, rather than as physically feasible power flows through specific transmission corridors. Coupling GCAM-China-v8 with detailed power-system or transmission-expansion models is an important direction for future work.

Revised text:

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."

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."*

6. Static spatial mappings: The mapping of provinces to water basins is fixed at 2010 values. This assumes spatial demand patterns remain unchanged for 50 years, ignoring the massive geographic shifts in industrial and urban activity projected by the model itself, which could mask future regional water stress.

Author's response: We thank the reviewer for pointing out this important limitation. We agree that the fixed 2010 province-to-basin mapping does not capture future changes in the spatial distribution of industrial activity, urbanization, population, and associated water demand. We have acknowledged this limitation in the revised manuscript. Future versions of GCAM-China will update the province-to-basin mapping data to better represent evolving demand patterns across provinces and water basins.

Revised text:

Section 4 Discussion and conclusions, the fifth paragraph: *"In addition, the water module relies on fixed 2010 province-to-basin mapping and therefore does not capture future shifts in population, urbanization, industrial activity, or water demand. This static mapping may therefore limit the interpretation of future regional water stress, especially in regions experiencing substantial socioeconomic or industrial shifts."*

Section 4 Discussion and conclusions, the seventh paragraph: *"Moreover, future versions of GCAM-China will update the province-to-basin mapping data to better represent evolving demand patterns across provinces and water basins."*

7. **LCOE curve parametrization**: Provincial supply curves for wind and solar are shaped by three parameters: MaxResource, MidPrice, and CurveEx. The paper needs more explanation on how grid-cell technical potentials (10km x 10km) were aggregated into these specific parameters. Specifically, how were land-use restrictions and terrain constraints weighted when moving from a high-resolution grid to a provincial-level curve?

Author's response: We thank the reviewer for this helpful comment. We have provided a detailed description of how high-resolution grid-cell renewable resource assessments are aggregated into provincial GCAM supply-curve parameters, and how land-use restrictions and terrain constraints are incorporated in this procedure. A supplementary Table SM10 summarizing the land-use restrictions and terrain constraints on deployment of utility-scale solar PV and onshore wind power stations selected in this study has also been added in Supplementary Material.

Revised text

Section 2.5.5 Resource: *"These studies estimate technically developable solar and wind potential in 10 km × 10 km grid cells, by accounting for site-specific resource quality and deployment constraints, including solar irradiance, wind speeds, terrain, and land-use constraints. Solar irradiance and wind speeds determine grid-cell resource quality, capacity factors, electricity generation potential. As for terrain, and land-use constraints, for utility-scale solar PV, we excluded grid cells with slopes exceeding 5% and assigned the remaining land suitability weights ranging from 0 to 20%, depending on the land-use category (Lu et al., 2021; Chen et al., 2019a). For onshore wind, we removed forested land, water bodies, permanent wetlands, snow and ice, and urban or built-up areas (Chen et al., 2024; Lu et al., 2009a; McElroy et al., 2009), along with locations where slopes exceeded 20% or capacity factors fell below 10%, retaining only those with a minimum technically feasible wind yield. Table SM10 summarizes the land-use restrictions and terrain constraints on deployment of utility-scale solar PV and onshore wind power stations selected in this study. Grid-cell levelized cost of electricity (LCOE) is then used to construct provincial renewable energy resource supply curves using the Eq. (8). Within each province, cells are ranked by LCOE, and their weighted potentials are cumulatively summed to form an empirical provincial LCOE-potential curve."*

Supplementary Material, Table SM10: *Constraints on deployment of utility-scale solar PV and onshore wind power stations selected in this study*

Natural constraints		***Setting for utility-scale solar PV power stations*** *(Chen et al., 2019b)*	***Setting for wind power stations****(Lu et al., 2009b)*
Suitability factor of	*All forest*	*0*	*0*
	Closed shrublands, woody savannas	*5*	*100*

land use (%)	*Grasslands, open shrublands, savannas*	*20*	*100*
	Barren or sparsely vegetated	*20*	*100*
	Croplands, cropland/natural vegetation mosaic	*2*	*100*
	Urban and built-up	*5*	*0*
	Water bodies, permanent wetlands, snow, and ice	*0*	*0*
Slope (%)		*<5*	*<20*

8. Disaggregation gaps in non-CO_2 emissions: China is the world's largest emitter of methane, largely from coal sector followed by agriculture. For a model focused on provincial transition pathways, leaving out the largest methane sources (e.g., coal mine methane and rice cultivation) from the provincial resolution is a significant omission.

Author's response: We agree that coal mine methane and rice-cultivation methane are major methane sources in China and are important for provincial transition analysis. In the current version of GCAM-China-v8, these sources are retained in national-level non-CO_2 emissions accounting but are not yet disaggregated to the provincial level. We have revised Sections 2.6.3 and 3.2 to clarify that the current province-resolved non- CO_2 emissions module focuses on emissions from energy end use and related sectoral sources that are already implemented at provincial resolution. We also clarified that major methane sources such as coal mine methane and rice-cultivation methane remain represented at the national level only.

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." ...*

3.2 Non-CO_2 greenhouse gas emissions, the first paragraph: *"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)."*

3.2 Non-CO_2 greenhouse gas emissions, Figure 12 caption: *"Figure 12: National non- CO_2 emissions and province-resolved energy end-use and related non- CO_2 emissions under the REF and CN scenarios."*

9. **CCS storage and CO_2 transport:** Several types of CCS technologies are mentioned, such as CCS in energy supply, industries and CDR technologies. However, it's not mentioned how the provincial geological storage potential is applied in the calculation. The assumptions such as cumulative CCS and geological capacity relationship and annual constraints are unclear. Furthermore, mismatch in source of carbon capture and destination of geological storage, as well as geological storage limitation in a particular province would require CO_2 transport between provinces. Such mechanisms are not described.

Author's response: Thank you for this important comment. We agree that the manuscript did not sufficiently explain how provincial geological CO_2 storage potential is applied or how annual storage limits and CO_2 transport are treated. We have added Section 2.6.2 Geological CO_2 Storage and Transport Representation to clarify these assumptions.

Revised text:

Section 2.6.2 Geological CO_2 storage and transport representation : *"Geological CO_2 storage in GCAM-China-v8 is represented using province-level onshore cost-capacity supply curves. These curves are constructed from storage-option datasets based on Dahowski et al. (2010, 2017), which provide cost and capacity estimates for geological CO_2 storage options in China. Within each province, storage options are sorted by cost, cumulatively summed by capacity, and discretized into six storage grades. Storage potential is represented as cumulative geological capacity rather than as an annual injection-rate constraint. Captured CO_2 from fossil CCS, industrial CCS, BECCS, and other CCS/CDR applications using onshore storage draws on the available provincial storage supply curve over time. In this study, onshore storage is represented through province-level storage markets, so cross-provincial substitution of onshore storage capacity is not represented. Source-sink mismatch is reflected as a provincial storage-availability and storage-cost constraint."*

10. Hydrogen and its derivatives: Hydrogen shows a significant share in industry and transport sector in the Carbon Neutrality scenario. The energy production methods from hydrogen and its derivatives (synthetic fuels, ammonia) are not described.

Author's response: Thank you for this important comment. We have added the model description to cover the hydrogen supply chain, from production through transport, delivery, and dispensing to end use, and provided an overview of hydrogen-related technology options in the manuscript and Supplementary Material files.

Revised text:

Section 2.5.2 Industry, the fifth paragraph: *"In GCAM-China-v8, hydrogen is produced through centralized, industrial on-site, and forecourt pathways, including biomass-, coal-, and natural-gas-based production with or without CCS, as well as electrolysis powered by grid, nuclear, solar, or wind electricity. Hydrogen is transported by pipeline or liquid-hydrogen truck and supplied to end users through wholesale and industrial delivery networks and retail dispensing stations. It is used as an energy carrier in industrial processes and transport technologies. Detailed representations of these pathways and technologies are provided in Tables SM11-13."*

Supplementary Material, Table SM11: Hydrogen production pathways represented in GCAM-China-V8

Model sector	***Model subsector***	***Model technology***
H_2 central production	*biomass*	*biomass to H2*
H_2 central production	*biomass*	*biomass to H2 CCS*
H_2 central production	*coal*	*coal chemical CCS*
H_2 central production	*electricity*	*electrolysis*
H_2 central production	*gas*	*gas ATR CCS*
H_2 central production	*gas*	*natural gas steam reforming*
H_2 central production	*nuclear*	*electrolysis*
H_2 central production	*solar*	*electrolysis*
H_2 central production	*wind*	*electrolysis*
H_2 industrial	*onsite production*	*electrolysis*
H_2 wholesale dispensing	*forecourt production*	*electrolysis*
H_2 wholesale dispensing	*forecourt production*	*natural gas steam reforming*

Table SM12. Hydrogen transport, delivery, and dispensing pathways represented in GCAM-China-v8

Supply-chain stage	***Model sector***	***Model subsector***	***Model technology***	***Hydrogen type***
Bulk transport from centralized production	*H_2 liquid truck*	*H_2 liquid truck*	*H_2 liquid truck*	*H_2 central production*
Bulk transport from centralized production	*H_2 pipeline*	*H_2 pipeline*	*H_2 pipeline*	*H_2 central production*
Wholesale delivery	*H_2 wholesale delivery*	*H_2 liquid truck*	*H_2 liquid truck*	*H_2 liquid truck*
Wholesale delivery	*H_2 wholesale delivery*	*H_2 pipeline*	*H_2 pipeline*	*H_2 pipeline*
Wholesale dispensing	*H_2 wholesale dispensing*	*H_2 delivery*	*H_2 liquid truck*	*H_2 liquid truck*
Wholesale dispensing	*H_2 wholesale dispensing*	*H_2 delivery*	*H_2 pipeline*	*H_2 pipeline*
Industrial delivery	*H_2 industrial*	*H_2 delivery*	*H_2 delivery*	*H_2 wholesale delivery*
Retail dispensing	*H_2 retail dispensing*	*H_2 retail dispensing*	*H_2 retail dispensing*	*H_2 wholesale dispensing*

Table SM13. Hydrogen-related end-use technologies represented in GCAM-China-V8

Utilization category	Model sector	Model subsector	Model technology	Hydrogen type
Agriculture	agricultural energy use	hydrogen	hydrogen	H_2 industrial
Industry	ammonia	hydrogen	hydrogen	H_2 industrial
	biomass liquids	biomass liquids	BTL with hydrogen	H_2 industrial
	chemical energy use	hydrogen	hydrogen	H_2 industrial
	construction energy use	hydrogen	hydrogen	H_2 industrial
	iron and steel	EAF with DRI	Hydrogen-based DRI	H_2 industrial
	mining energy use	hydrogen	hydrogen	H_2 industrial
	other industrial energy use	hydrogen	hydrogen	H_2 industrial
	other industrial energy use	hydrogen	hydrogen cogen	H_2 wholesale delivery
	process heat cement	hydrogen	hydrogen	H_2 industrial
Transport	trn_aviation_intl	International Aviation	Hydrogen	H_2 wholesale dispensing
	trn_freight	Domestic Ship	FCEV	H_2 wholesale dispensing
	trn_freight	Freight Rail	FCEV	H_2 wholesale dispensing
	trn_freight_road	Heavy truck	FCEV	H_2 retail dispensing
	trn_freight_road	Light truck	FCEV	H_2 retail dispensing
	trn_freight_road	Medium truck	FCEV	H_2 retail dispensing
	trn_pass	Domestic Aviation	Hydrogen	H_2 wholesale dispensing
	trn_pass_road	Bus	FCEV	H_2 retail dispensing
	trn_pass_road_LDV_4W	Car	FCEV	H_2 retail dispensing
	trn_pass_road_LDV_4W	Large Car and Truck	FCEV	H_2 retail dispensing
	trn_pass_road_LDV_4W	Mini Car	FCEV	H_2 retail dispensing
	trn_shipping_intl	International Ship	FCEV	H_2 wholesale dispensing

11. **Results vs historical data**: Likewise figure 15, major variables of energy system, land-use and agriculture should be compared with statistical values. Further, there should be some explanations why calibration year has gap with statistical record in emissions.

Author's response: We thank the reviewer for this constructive comment. We have added comparisons between modeled outputs and historical statistics for key energy-system variables. For land use and agriculture, GCAM-China-v8 follows the core GCAM framework, with these sectors remaining calibrated at the national or basin level. Therefore, they cannot yet be directly compared with provincial statistical records.

In addition, we have also supplemented the explanation for the remaining calibration-year emission differences relative to inventory data.

Revised text:

Section 3.5 Comparison to historical data, the third paragraph： *"The remaining differences between GCAM-China-v8 and the historical emissions inventory should be interpreted considering differences in data sources, accounting boundaries, and model calibration procedures. GCAM-China-v8 is calibrated to harmonized historical energy activity data and internally consistent sector-fuel mappings, rather than directly fitted to a single emissions inventory. Residual differences relative to MEIC may arise from the reconciliation of multiple energy datasets, differences in sectoral and fuel classifications, treatment of non-energy uses, accounting boundaries(Guan et al., 2012), calorific values, carbon contents(Liu et al., 2015), and oxidation rates (Eggelston et al., 2006). These factors are particularly important for coal-related emissions and have been identified as major sources of variation among Chinese emissions inventories."*

Section 3.5 Comparison to historical data, the fourth and the fifth paragraph*: "We further compare modelled provincial solar, wind, and coal-fired generation with historical statistics for 2015 and 2021 (Fig.16). Historical provincial generation is shown on the x-axis and GCAM-China-v8 REF values on the y-axis, together with a 1:1 line and a ±5% deviation band. Historical provincial solar, wind, and thermal generation data are obtained from the China Energy Statistical Yearbook (National Bureau of Statistics of China, 2022). Because consistent provincial coal-fired generation statistics are not directly available, historical coal-fired generation is estimated from provincial thermal generation and the corresponding national coal-fired share.*

For solar generation, the number of provinces within ±10% of historical values is 9 in 2015 and 25 in 2021, while 8 and 25 provinces, respectively, fall within ±5%. Provincial solar generation shows larger relative deviations in 2015, particularly among provinces with low historical generation, where small absolute differences can result in substantial percentage deviations. In 2021, most provincial values are distributed closer to the 1:1 line, although the model underestimates generation in several provinces with relatively high solar output. For wind generation, 17 and 31 provinces are within ±10% in 2015 and 2021, respectively, and 13 and 31 provinces are within ±5%. The 2015 results show relatively dispersed provincial values, whereas the 2021 results cluster more closely around the 1:1 line. For coal-fired generation, the number of provinces within ±10% is 27 in 2015 and 30 in 2021, with 11 and 29 provinces within ±5%, respectively. Most major coal-generating provinces are distributed close to the 1:1 line, although deviations remain for some provinces."

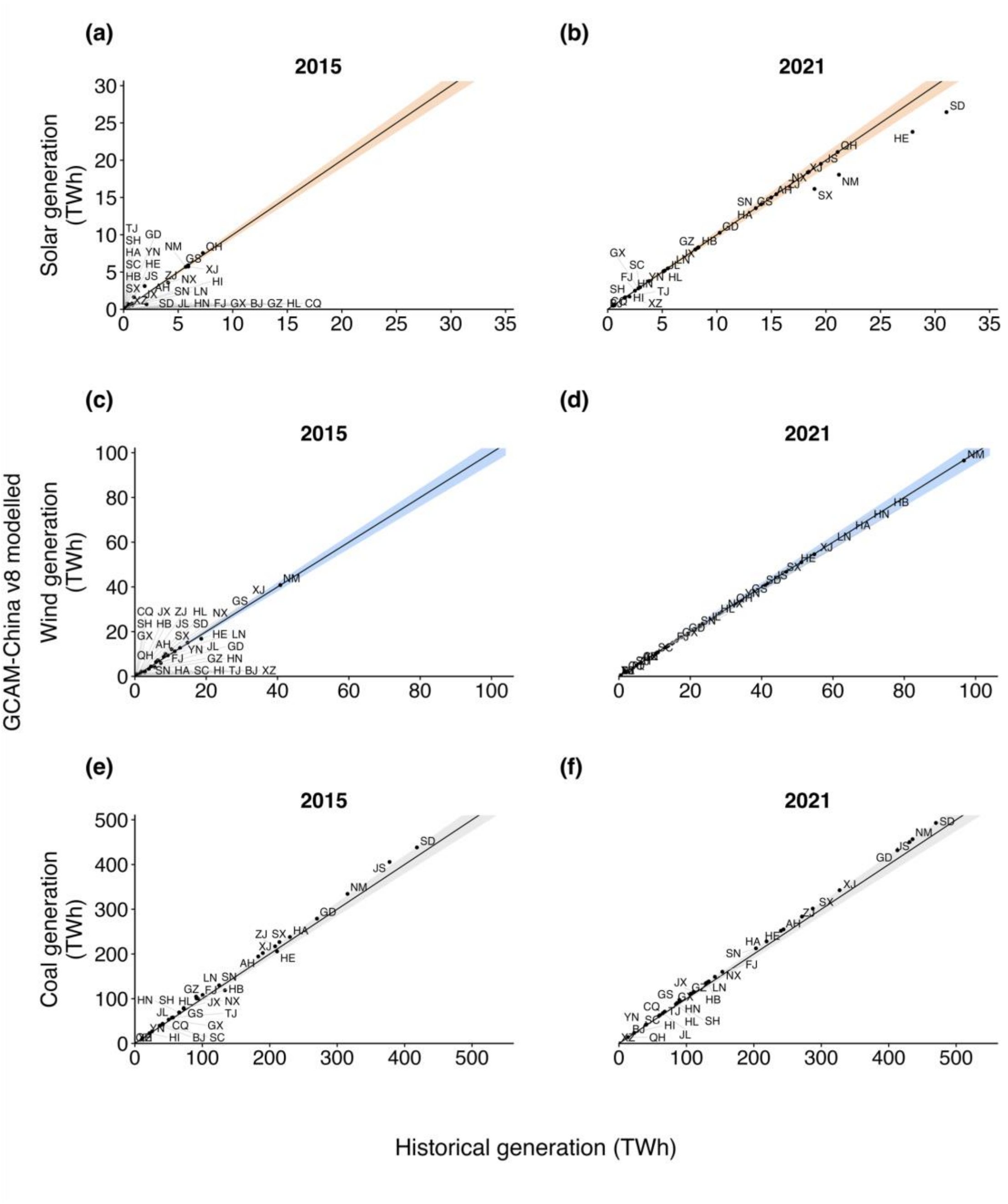

Figure 16. Comparison of GCAM-China-v8 modelled and historical provincial electricity generation by technology in 2015 and 2021.

12. **No vintage in building sector**: The building sector uses a Gompertz function to relate floorspace to income, but it does not include building vintaging. This means existing building stock is treated the same as new construction. The model's inability to represent the inertia of existing insulation and efficiency levels needs more justification. How does the model prevent unrealistic, instantaneous improvements in building efficiency across the entire provincial stock?

Author's response:

We thank the reviewer for raising this important limitation. GCAM-China-v8 does not explicitly represent building vintages or distinguish existing buildings from new construction. In the current version, we approximate the representation of building-stock inertia through floorspace constraints and stock-average building-shell efficiency parameters. We have revised the manuscript to clarify these treatments and to acknowledge that the model does not explicitly represent renovation dynamics, vintage-specific efficiency, or endogenous stock turnover. Future versions of GCAM-China will aim to incorporate explicit building-stock vintaging and renovation dynamics as data availability improves (Mastrucci et al., 2025; Vivier et al., 2025).

Revised text:

Section 2.5.3 Building, the second and the third paragraph:

"To prevent this, the model imposes a constraint on floorspace for each consumer group, so that it does not fall below its final calibration year level regardless of future income fluctuations."

"η represents stock-average building-shell conductivity and determines the thermal efficiency of building envelopes. Building-stock inertia is approximated using an exogenous trajectory in which conductivity declines gradually until 2050 and remains constant thereafter, preventing instantaneous efficiency improvements across the provincial building stock. This reduced-form approach does not explicitly represent renovation or vintage-specific stock turnover is the building shell conductivity, representing the thermal efficiency of building envelopes."

Section 4 Discussion and conclusions, the seventh paragraph: ... *"Explicit building-stock vintaging, as used in detailed building-sector models such as MESSAGE-Buildings (Mastrucci et al., 2025; Vivier et al., 2025), is important for representing the inertia of building-sector decarbonization and will be an important direction for future GCAM-China development."* ...

13. Top-down vs bottom-up: While the major attraction of the model is disaggregation into provincial scale, calculations involve both top-down and bottom-up approaches. Sectoral energy consumptions are reconciled with the IEA Energy Balances, which are further used to estimate the sectoral non-CO_2 emissions. This erases the provincial nuances and reliability on such scale. The implications of such mixed approaches should be critically addressed.

Author's response: Thank you for this important comment. We revised the manuscript to clarify that the reconciliation with IEA Energy Balances does not erase provincial spatial patterns. For each subsector-fuel category, a common scaling factor is applied to all provinces, so the provincial shares derived from the bottom-up MEIC-HR data are preserved. We added Table SM9 to show that provincial shares remain unchanged before and after reconciliation. We also acknowledge the implication of this mixed top-down/bottom-up approach. Provincial absolute energy-consumption and related non-CO_2 emission levels are constrained by the IEA national benchmark. This approach is better suited for assessing relative provincial distributions and scenario-driven changes. In addition, the validation results in Section 3.5 show that, when national totals are well aligned with statistical benchmarks, GCAM-China-v8 represents historical provincial-level patterns in CO_2 emissions and key energy-system variables reasonably well. This provides additional evidence that the reconciliation procedure preserves the main spatial patterns represented in the bottom-up provincial inventory.

Revised Text:

Section 2.5.2 Industry, the second paragraph: *"To maintain international consistency, sectoral total energy consumption is reconciled with IEA Energy Balances when MEIC-HR facility-level data inconsistent with IEA sectoral totals. For each sector, a scaling factor calculated at the national level is applied uniformly to all provinces, thereby preserving their relative energy-consumption shares and the provincial heterogeneity represented in MEIC-HR. Tabel SM9 shows an illustrative subsector-fuel example with the original MEIC-HR provincial values, the scaling factor, reconciled values, and provincial shares before and after reconciliation. However, while relative provincial patterns are preserved, absolute provincial values are constrained by national benchmarks and may not fully capture local statistical nuances."*

Supplementary Material, Table SM9:

Table SM9. Provincial energy-consumption shares before and after national-level reconciliation

Province	Supply sector	Energy input	Scale factor	MEIC-HR bottom-up amount (EJ)	Percentage in total before	Reconciled amount (EJ)	Percentage in total after
AH	chemical energy use	elect_td_ind	1.6	0.007	2.71%	0.012	2.71%
BJ	chemical energy use	elect_td_ind	1.6	0.002	0.72%	0.003	0.72%
CQ	chemical energy use	elect_td_ind	1.6	0.006	2.08%	0.009	2.08%
FJ	chemical energy use	elect_td_ind	1.6	0.004	1.56%	0.007	1.56%
GD	chemical energy use	elect_td_ind	1.6	0.007	2.50%	0.011	2.50%
GS	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
GX	chemical energy use	elect_td_ind	1.6	0.004	1.40%	0.006	1.40%
GZ	chemical energy use	elect_td_ind	1.6	0.005	1.73%	0.008	1.73%

HA	chemical energy use	elect_td_ind	1.6	0.016	5.89%	0.026	5.89%
HB	chemical energy use	elect_td_ind	1.6	0.005	1.85%	0.008	1.85%
HE	chemical energy use	elect_td_ind	1.6	0.035	12.56%	0.055	12.56%
HI	chemical energy use	elect_td_ind	1.6	0.004	1.30%	0.006	1.30%
HL	chemical energy use	elect_td_ind	1.6	0.007	2.60%	0.011	2.60%
HN	chemical energy use	elect_td_ind	1.6	0.003	1.06%	0.005	1.06%
JL	chemical energy use	elect_td_ind	1.6	0.004	1.41%	0.006	1.41%
JS	chemical energy use	elect_td_ind	1.6	0.020	7.27%	0.032	7.27%
JX	chemical energy use	elect_td_ind	1.6	0.004	1.60%	0.007	1.60%
LN	chemical energy use	elect_td_ind	1.6	0.016	5.86%	0.026	5.86%
NM	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
NX	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
QH	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
SC	chemical energy use	elect_td_ind	1.6	0.003	1.14%	0.005	1.14%
SD	chemical energy use	elect_td_ind	1.6	0.044	15.84%	0.070	15.84%
SH	chemical energy use	elect_td_ind	1.6	0.011	3.91%	0.017	3.91%
SN	chemical energy use	elect_td_ind	1.6	0.011	4.16%	0.018	4.16%
SX	chemical energy use	elect_td_ind	1.6	0.046	16.72%	0.074	16.72%
TJ	chemical energy use	elect_td_ind	1.6	0.005	1.84%	0.008	1.84%
XJ	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
XZ	chemical energy use	elect_td_ind	1.6	0.000	0.00%	0.000	0.00%
YN	chemical energy use	elect_td_ind	1.6	0.001	0.31%	0.001	0.31%
ZJ	chemical energy use	elect_td_ind	1.6	0.006	1.99%	0.009	1.99%

Note: The same scaling factor (1.6) is applied uniformly to all provinces within the selected subsector–fuel category. The reconciled amounts are therefore proportional to the original MEIC-HR bottom-up amounts, and provincial shares remain unchanged except for rounding.

Section 3.5 Comparison to historical data

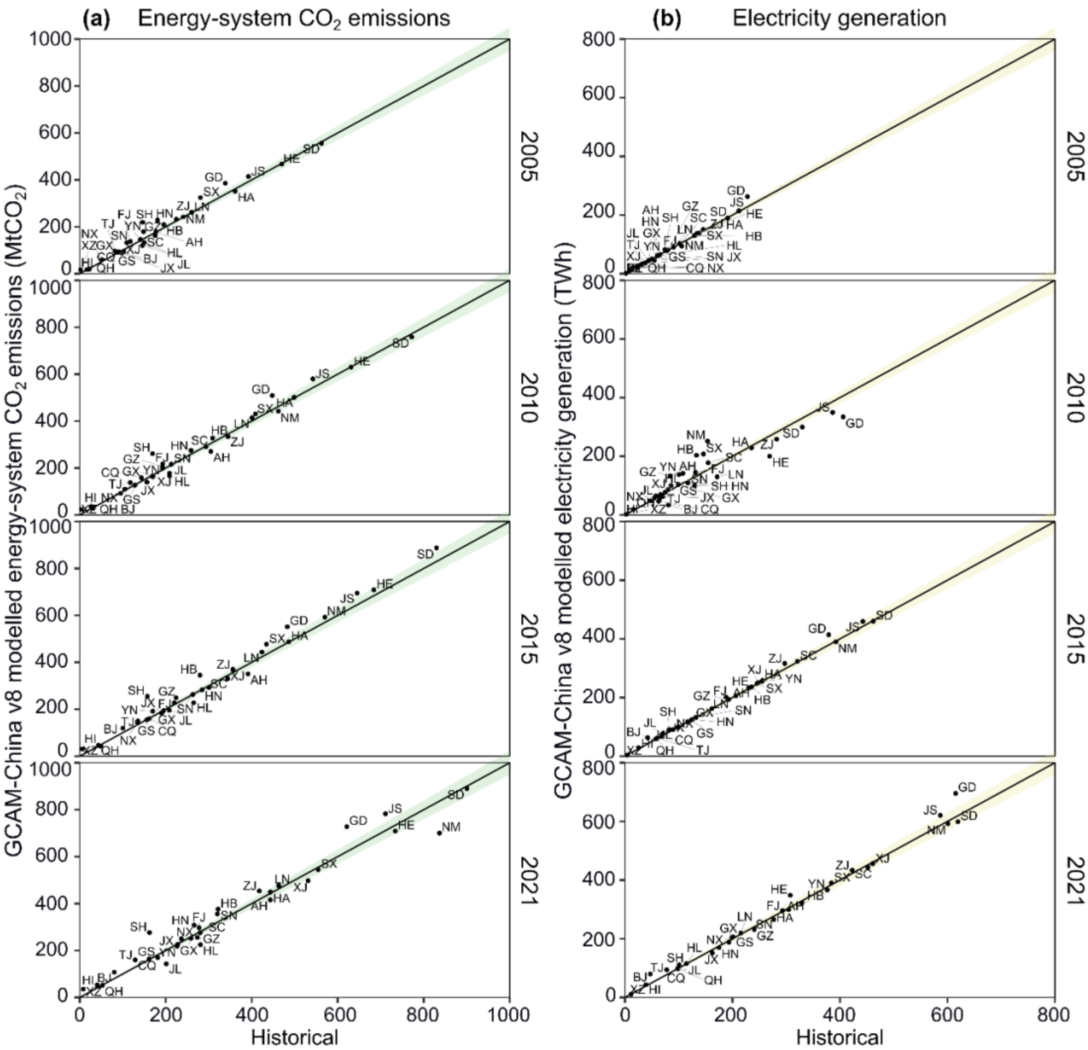

Figure 15: GCAM-China-v8 results versus historical inventory data.

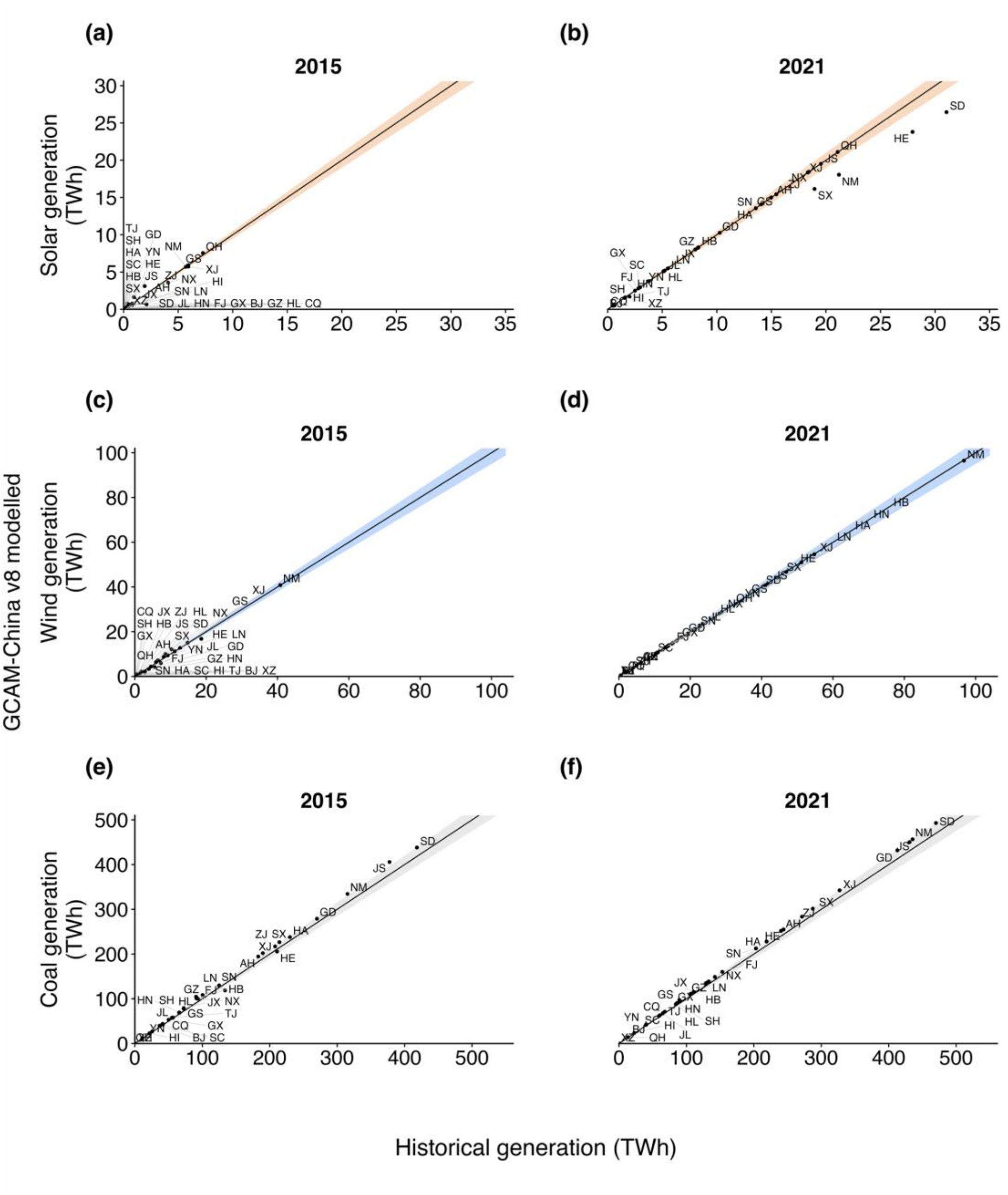

Figure 16. Comparison of GCAM-China-v8 modelled and historical provincial electricity generation by technology in 2015 and 2021.

Supplementary Material, Section Evaluation of GCAM-China-v8 scenario projections against recent trends and developments:

"To assess the consistency of GCAM-China-v8 scenario projections with recent trends and developments, we introduced a supplementary "Current policy"-NetZero scenario to

characterize technology deployment and emissions-reduction trajectories under explicitly specified policy and emissions constraints and compared selected model outputs with historical statistics. This scenario provides a policy- and emissions-constrained pathway for evaluating how GCAM-China-v8 represents technology deployment and emissions reductions under current policy assumptions and China's long-term carbon-neutrality target.

The "Current policy"-NetZero scenario follows the design of Wang et al. (2026). It applies the Current-BAU policy pathway, which incorporates national policies adopted through 2025 and extrapolates these measures to 2030. No further strengthening of policies is assumed after 2030. Starting from 2040, a binding linear CO_2 decline constraint is imposed, reaching carbon neutrality by 2060.

We benchmarked selected model outputs against historical data and external statistical estimates for China's CO_2 emissions, electricity-generation mix, and BEV deployment (Figure SM1). The comparison shows that national CO_2 emissions in the "Current policy"-NetZero scenario are close to recent estimates from GCP and EDGAR over the overlapping years. The modeled generation shares of nuclear, solar, and wind power also broadly align with historical values in the overlapping period and increase thereafter under the combined effects of current policy assumptions and the long-term CO_2 decline constraint. For BEVs, the comparison is based on the BEV share in the LDV stock rather than the new-sales share. Historical data show a gradual increase in the BEV stock share during 2021-2025, and the "Current policy"-NetZero scenario projects continued expansion after 2025, indicating that GCAM-China-v8 represents the progressive electrification of the LDV stock. Because vehicle stock turnover is gradual, the BEV stock share naturally lags the more rapidly changing new-sales share."

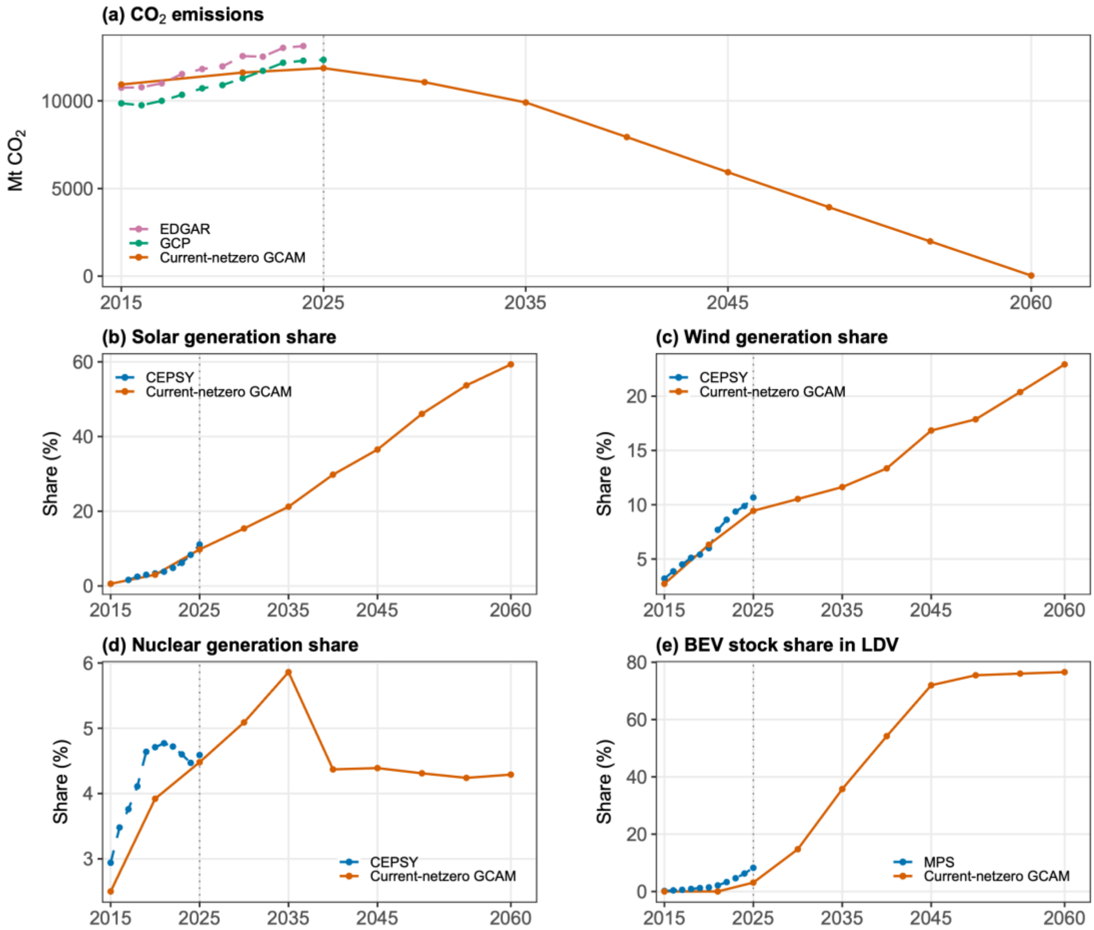

Figure SM1. Comparison of GCAM-China-v8 "Current policy"-NetZero scenario results with historical and external estimates for selected indicators in China.

Notes: Panels show (a) CO_2 emissions, (b) solar generation share, (c) wind generation share, (d) nuclear generation share, and (e) BEV stock share in the LDV fleet. Solid lines indicate GCAM-China-v8 "Current policy"-NetZero scenario results, while dashed lines indicate historical statistics or external estimates. The "Current policy"-NetZero scenario represents a pathway in which near-term socioeconomic, energy, and technology assumptions follow current-policy settings through 2025, with a carbon-neutrality constraint introduced from 2040 onward to achieve net-zero CO_2 emissions by 2060. CO_2 emissions are compared with estimates from the Global Carbon Project (GCP; Andrew and Peters, 2025) and the Emissions Database for Global Atmospheric Research (EDGAR; European Commission. Joint Research Centre., 2025). Solar, wind, and nuclear generation shares are calculated from national power generation statistics reported in China Electric Power Statistical Yearbook (China Electricity Council, 2025) and Statistical Communiqué of the People's Republic of China on the National Economic and Social Development (National Bureau of Statistics of China, 2025). BEV stock shares are calculated from vehicle stock statistics released by the Ministry of Public Security of the People's Republic of China (MPS; 2025). The vertical dotted line marks 2025. The "Current policy"-NetZero scenario outputs are available through the accompanying Zenodo repository at https://doi.org/10.5281/zenodo.21981604.

14. **Lack of critical analysis in discussion**: While Section 4 lists model limitations, it lacks a critical analysis of how the methodological choices impact the findings. Specifically, the authors should explicitly delineate the boundaries of the model's utility, guiding readers/users on the contexts where its provincial-level insights are most robust and where structural simplifications necessitate a cautious interpretation of its projected transition pathways.

Author's response: Thank you for this insightful comment. We have substantially revised Section 4 to provide a more critical discussion of the model's utility boundaries of the provincial-level findings from GCAM-China-v8.

Revised Text:

Section 4 Discussion and conclusions, the third paragraph: *"The provincial-level results should be interpreted within the utility boundaries of an integrated assessment model. Like other IAMs, GCAM-China-v8 is not intended to predict a single future or reproduce all observed provincial statistics exactly. Its strength lies in producing internally consistent, long-term transition pathways under alternative assumptions about socioeconomic development, technology availability, energy prices, resource endowments, and climate policy. The results are therefore most useful for comparing scenarios, identifying relative differences across provinces, and locating where transition pressures, mitigation opportunities, or resource constraints are likely to be concentrated. They should not be interpreted as detailed provincial infrastructure plans or project-level feasibility assessments."*

Section 4 Discussion and conclusions, the fourth paragraph: *"Several structural simplifications in GCAM-China-v8 will affect how specific findings should be interpreted. As with most IAMs, GCAM-China-v8 is designed to assess long-term, economy-wide, cross-sectoral transition pathways rather than detailed power-system operations. This modeling scope is consistent with the broader methodological role of IAMs, which evaluate long-term structural transitions across sectors and regions rather than resolve sub-annual dispatch, transmission congestion, or grid stability constraints (Ou et al., 2021c). Such operational questions are typically examined by coupling IAMs with dedicated power-system planning or dispatch models (Yin et al., 2026b). Therefore, high wind and solar deployment should be interpreted as a long-term generation-mix outcome, not as an operationally validated power-system design. 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."*

Section 4 Discussion and conclusions, the fifth paragraph: *"Additional assumptions require cautious interpretation. Consistent with the core GCAM framework, GCAM-China-v8 does not endogenously represent internal migration decisions, province-specific demographic transitions, or locally driven economic restructuring. In addition, the water module relies on fixed 2010 province-to-basin mapping and therefore does not capture future shifts in population, urbanization, industrial activity, or water demand. This static mapping may therefore limit the interpretation of future regional water stress, especially in regions experiencing substantial socioeconomic or industrial shifts. 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 use, modeled national water totals may therefore differ from official statistics."*

Section 4 Discussion and conclusions, the seventh paragraph: *… "Moreover, future versions of GCAM-China will update the province-to-basin mapping data to better represent evolving demand patterns across provinces and water basins. Explicit building-stock vintaging, as used in detailed building-sector models such as MESSAGE-Buildings (Mastrucci et al., 2025; Vivier et al., 2025), is important for representing the inertia of building-sector decarbonization and will be an important direction for future GCAM-China development." …*

Minor comments

1. **Novelty in model development**: The paper mentions several versions of GCAM-China, some of which already considered provincial level development. However, the major advances of GCAM-China-v8 compared to previous GCAM-China versions are unclear in the abstract and introduction section. There should be an explicit mention regarding what are new developments in this version compared to previous versions.

Author's response: Thank you for pointing this out. We have revised the Abstract, Introduction, and the Section 2.3 Overview of GCAM-China to clarify the features inherited from earlier GCAM-China versions and major advances of the 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."

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="5">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>Provincial (31 provinces)</td><td>Emission-source technologies; fleet turnover; EOP controls</td><td>GCAM-China + MEIC + DPEC</td><td>Used in published studies; method, selected inputs/sce</td><td>Emission projections; climate–clean-air co-control; health assessment (Tong et al., 2020; Cheng et al., 2021, 2023)</td></tr>
</table>

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*	*narios/results available depending on study*	*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*		*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., 2020, 2019)*
GCAM-China-v7	*GCAM-China v7*	*2015*		*GCAM-Macro coupling added;* *high-resolution provincial wind and PV supply curves;* *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;* *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. **Visualizations**: The differences between the compared scenarios are not clear in figure 8, figure 9, figure 13. Adding a difference chart would be better for such small changes.

Author's response: Thank you for your suggestions. We have added the difference chart for figure 8, figure 9, figure 13, respectively.

Revised Figures:

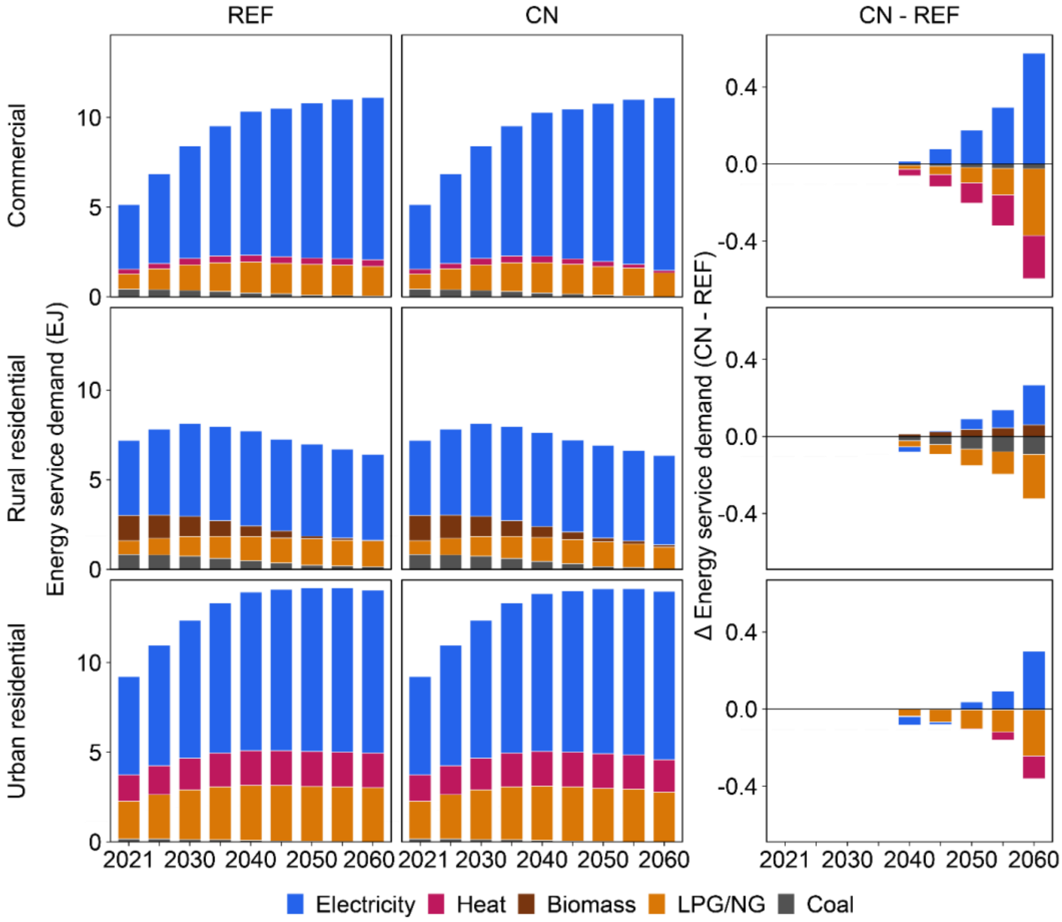

Figure 8: Energy service shares by fuel in the building sector.

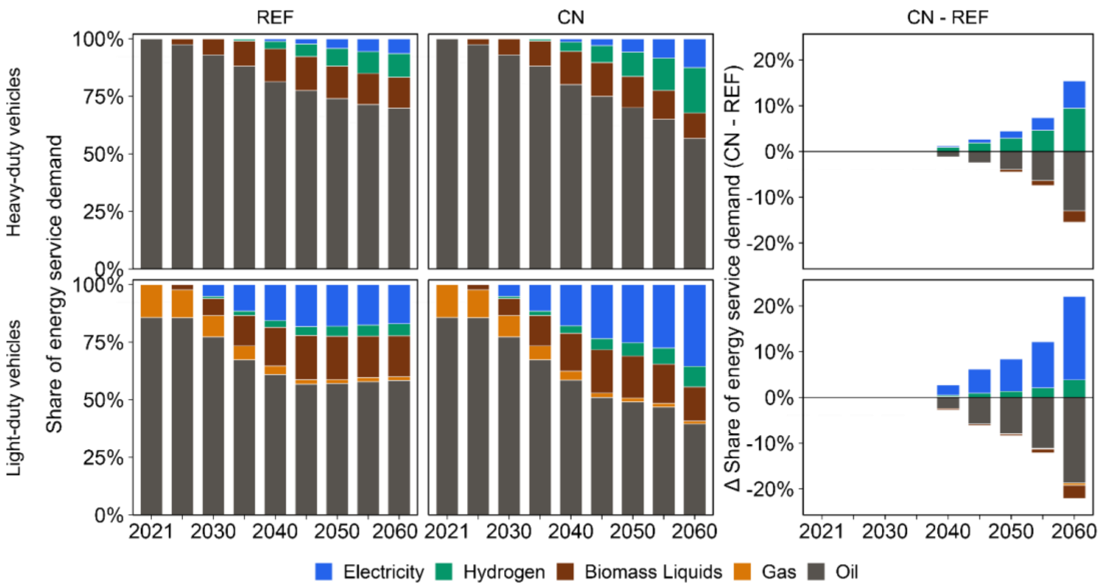

Figure 9: Energy service shares by fuel in light-duty and heavy-duty transport.

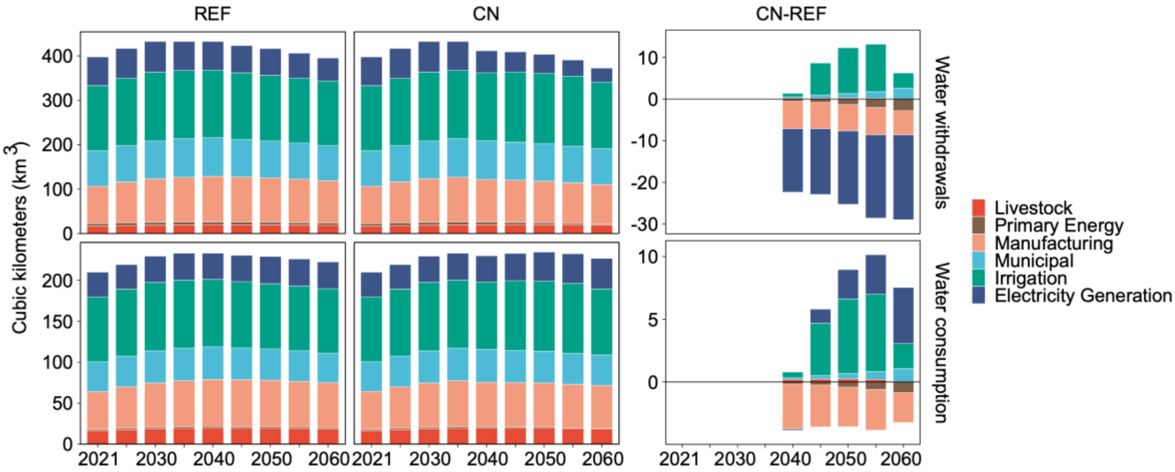

Figure 13: Water withdrawals and consumption by sector under REF and CN scenarios.

3. **Reproducibility**: Information required to reproduce the model simulation, such as system requirements, installation guides, specifications of environment on which model was run, simulation time, etc. are important for other users. It's better to have such information in the supplementary material.

Author's response: We thank the reviewer for this helpful suggestion. In response, we have added a new reproducibility section to the Supplementary Material file and summarized the key information required to reproduce the GCAM-China-v8 simulations in Table SM14.

Added section:

Supplementary Material, Reproducibility information: *"The key information required to reproduce the GCAM-China-v8 simulations in this study is summarized in Table SM14. It summarizes the key information required to reproduce the GCAM-China-v8 simulations presented in this study. The GCAM-China-v8 model release, the study-specific processing code, input files, configuration files, and output databases are archived on Zenodo (See Section Code and data availability). Existing GCAM and GCAM-China documentation materials are listed to support installation, model execution, and output inspection. These documentation resources provide user guidance and are complementary to the archived model release and study-specific materials."*

Table SM14. Reproducibility information for GCAM-China-v8 simulations

Item	***Information***
Model version	*GCAM-China v8*
Model archive / release DOI	*https://doi.org/10.5281/zenodo.19471594*
Supported release packages	*Windows and Mac release packages*

GCAM Eco-System Training Materials & Guides	*Training materials and guides for GCAM and GCAM Eco-system tools (Joint Global Change Research Institute, 2026)*
GCAM-China manual	*GCAM-China manual https://zenodo.org/records/15581183(Joint Global Change Research Institute, 2025)*
Prerequisite software	*Java; R*
Code, input files, configurations, and outputs in this research	*https://doi.org/10.5281/zenodo.21981604*
Simulation time	*Varies depending on hardware specifications, scenario settings, and output database options*