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# Mitigation scenarios for the global building sector: a model intercomparison study

*IAMC Abstract*  
*Session: SECTORAL*

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## **Summary**

Buildings are responsible for 21% of global greenhouse gas (GHG) emissions. Integrated Assessment Models (IAMs) used to analyse mitigation scenarios have key limitations in assessing demand-side interventions for the building sector. Here, we use a set of IAMs with improved buildings representation to explore a comprehensive set of mitigation scenarios for the global building sector, considering the effects of demand-side interventions and climate policies towards net-zero emissions. The results show that a combination of demand-side and supply-side interventions will be required to achieve ambitious climate targets.

## **1. Introduction**

Being responsible for 21% of global greenhouse gas (GHG) emissions (Cabeza et al., 2022), the building sector plays a key role in the transformations required to achieve climate mitigation goals<sup>1</sup>. Integrated Assessment Models (IAMs) are largely used to assess global climate change mitigation scenarios. IAMs, however, commonly have a strong focus on energy supply-side and limited representation of end-use sectors, including buildings, and demand-side interventions<sup>2</sup>. Capturing the heterogeneity of the building sector and relevant building dynamics is key for assessing sectoral mitigation strategies, but is limited in current global building sector modelling<sup>3</sup>.

The NAVIGATE project brought methodological advancements for an improved representation of the building sector in IAMs, including residential and services (commercial). These improvements made it possible to enhance the characterization of the building sector at global and regional scales and to assess a broader range of key demand-side decarbonization interventions, including: activity

reduction and shift; technological improvements and energy efficiency; and electrification and fuel shifts. We use these improved IAMs to explore a comprehensive set of mitigation scenarios for the global building sector considering the effects of demand-side interventions and climate policies towards net-zero emissions.

## 2. Methods and scenario setup

We assess the scenario implications by using a set of global established IAMs (ImacliM-R<sup>4,5</sup>, IMAGE<sup>6</sup>, MESSAGEix<sup>3,7</sup>, PROMETHEUS<sup>8</sup>, REMIND<sup>9</sup>, and WITCH<sup>10</sup>), integrating detailed building sector modules. The models use different approaches for modelling the building sector, namely top-down, bottom-up, or hybrid, and different representations of changes in energy service (e.g. floorspace), with change levers (e.g. preference factors) being either exogenous or endogenous. We ensure alignment between the different model implementations by using a common protocol indicating the basic scenario setup and considered interventions. The socio-economic projections underlying all scenarios are based on the Shared Socioeconomic Pathway SSP2 “Middle of the Road”.

We focus on three main sets of demand-side interventions for buildings and their combination:

1. **Activity reduction and activity shift (ACT)**, involving the redesign of service-provisioning systems to either reduce or shift consumptions, such as reduction in floorspace via co-housing and co-working, shift to multi-family houses, and change in heating and cooling setpoint temperatures.
2. **Technological improvements and energy efficiency (TEC)**, *focusing on improvements in the efficiency of existing technologies, including building shells and heating and cooling systems in new construction and renovation, and increase in the rate and depth of renovation.*
3. **Electrification and fuel shift (ELE)**, concerning a switch to *low-carbon technologies, including heat pumps and electricity-based systems while phased out fossil fuels*
4. **All interventions combined (ALL).**

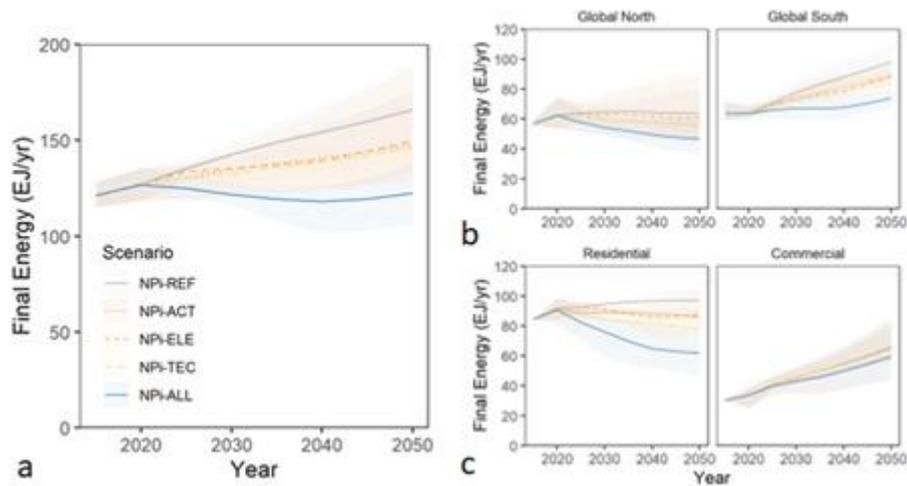
We investigate the effect of the above sets of demand-side interventions together with three *climate pathways* characterised by different levels of policy ambition and carbon pricing: continuation of current national policies with no stringent climate policies (NPi), climate policies consistent with 2 °C global warming targets (2.0C), and climate policies consistent with 1.5°C global warming targets (1.5C). We compare the results to a reference scenario (NPi-REF) with continuation of current demand-side and national climate policies.

## 3. Results

In the reference scenario (NPi-REF), the global final energy demand of buildings increases by 37.2% until 2050 (average across models) (Figure 1, panel a). The Global South is driving a large part of this increase under growing population and higher affluence levels, while energy efficiency improvements in the Global North largely counterbalance the increase in activities (Figure 1, panel b). The residential sector currently dominates the global buildings energy demand, but the commercial sector is projected to greatly increase energy demands until 2050 (Figure 1, panel c).

Demand-side interventions can significantly contribute to energy demand reductions. The effect of individual policies is similar, with an average reduction potential of 9.6% for NPi-ELE, 10.9% for NPi-ACT, and 12.1% for NPi-TEC compared to the reference NPi-REF in 2050. The highest energy demand reduction potential of 26.2% by 2050 can be achieved by combining the three demand-side policies, due to their high level of complementarity. These results are robust across the different models, but differences exist regarding the magnitude of the reduction and the ordering of contribution across different individual demand-side policies. The spread across models is lower for all policies

combined (NPi-ALL), while it is relatively higher in the case of activity shifts (NPi-ACT) and electrification (NPi-ELE).



*Figure 1: Global buildings final energy demand projections for different sectoral policy scenarios (NPi). Panel a: global energy demand (lines indicate models average, shaded areas indicate models ranges). Panel b: energy demand in the Global South and Global North. Panel c: energy demand in residential and commercial buildings.*

In the NPi-REF scenario, global total (direct and indirect) CO<sub>2</sub> emissions from buildings increase on average by 7.7% until 2050 (Figure 2, panel a). Implementing all demand-side policies (NPi-ALL) contributes to reducing CO<sub>2</sub> emissions on average by 22.7% compared to the reference scenario (NPi-REF) in 2050, including direct and indirect emissions. Larger reductions can be achieved by combining demand-side policies with more stringent climate policies, up to 83.0% in the 2.0C-ALL scenario and 91.3% in the 1.5C-ALL scenario in 2050, largely driven by the decarbonization of heat and electricity in indirect emissions. Residual direct emissions persist in the 2.0C-ALL and 1.5C-ALL scenarios by 2050, due to the continuing use of fossil fuels, especially for heating. The different models are generally in agreement on the total emissions results for the different scenarios (Figure 2, panel b). Larger spreads across models exist in the NPi scenarios, while those are substantially reduced under stringent climate policies (2.0C and 1.5C).

The results of this study show that combining a range of demand-side interventions and ambitious climate policies is required to decarbonize the global building sector. This study can support decision making on decarbonisation strategies at the global and regional level, and contribute to advancements towards net-zero emission targets for the building sector.

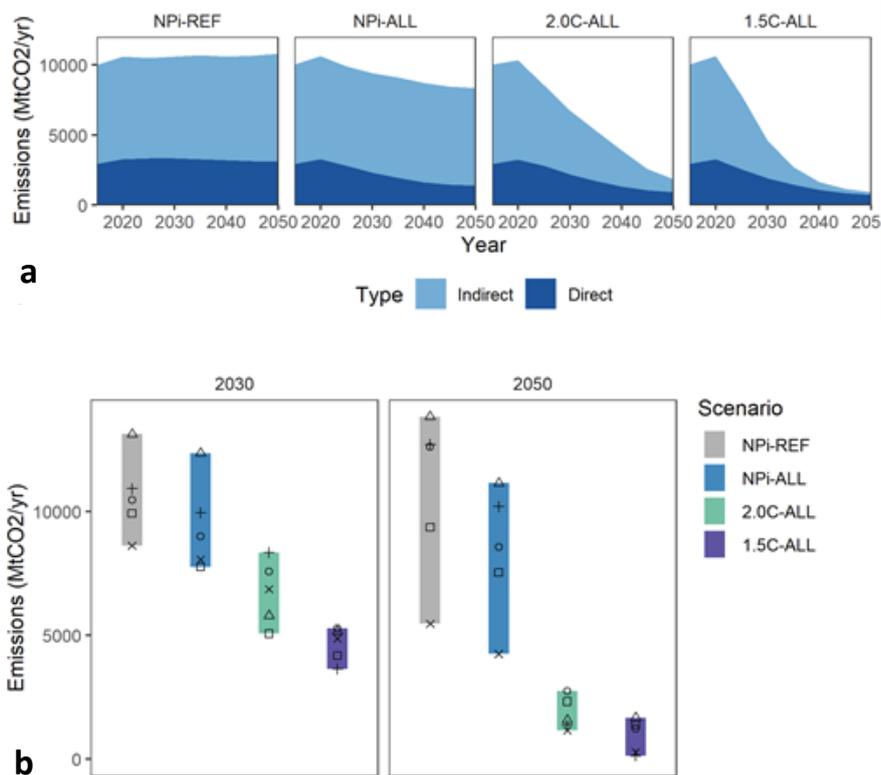


Figure 2: Global buildings CO<sub>2</sub> emission projections combining different sectoral and climate policy scenarios. Panel a: global total CO<sub>2</sub> emissions (direct and indirect, average across models). Panel b: CO<sub>2</sub> emissions in 2030 and 2050 across models (bars indicate result ranges across models, points indicate single model results).

## References

- (1) IEA. 2019 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector; 2019; p 41.
- (2) Creutzig, F.; Roy, J.; Lamb, W. F.; Azevedo, I. M. L.; Bruine de Bruin, W.; Dalkmann, H.; Edelenbosch, O. Y.; Geels, F. W.; Grubler, A.; Hepburn, C.; Hertwich, E. G.; Khosla, R.; Mattauch, L.; Minx, J. C.; Ramakrishnan, A.; Rao, N. D.; Steinberger, J. K.; Tavoni, M.; Ürge-Vorsatz, D.; Weber, E. U. Towards Demand-Side Solutions for Mitigating Climate Change. *Nature Clim Change* **2018**, 8 (4), 260–263. <https://doi.org/10.1038/s41558-018-0121-1>.
- (3) Mastrucci, A.; van Ruijven, B.; Byers, E.; Pobleto-Cazenave, M.; Pachauri, S. Global Scenarios of Residential Heating and Cooling Energy Demand and CO<sub>2</sub> Emissions. *Climatic Change* **2021**, 168 (3–4), 14. <https://doi.org/10.1007/s10584-021-03229-3>.
- (4) CIRED/SMASH. Model Documentation - IMACLIM, 2016. [https://www.iamcdocumentation.eu/index.php/Model\\_Documentation\\_-\\_IMACLIM](https://www.iamcdocumentation.eu/index.php/Model_Documentation_-_IMACLIM).
- (5) Méjean, A.; Guivarch, C.; Lefèvre, J.; Hamdi-Cherif, M. The Transition in Energy Demand Sectors to Limit Global Warming to 1.5 °C. *Energy Efficiency* **2019**, 12 (2), 441–462. <https://doi.org/10.1007/s12053-018-9682-0>.
- (6) Daioglou, V.; Mikropoulos, E.; Gernaat, D.; van Vuuren, D. P. Efficiency Improvement and Technology Choice for Energy and Emission Reductions of the Residential Sector. *Energy* **2022**, 243, 122994. <https://doi.org/10.1016/j.energy.2021.122994>.
- (7) Huppmann, D.; Gidden, M.; Fricko, O.; Kolp, P.; Orthofer, C.; Pimmer, M.; Kushin, N.; Vinca, A.; Mastrucci, A.; Riahi, K.; Krey, V. The MESSAGE Integrated Assessment Model and the Ix Modeling Platform (Ixmp): An Open Framework for Integrated and Cross-Cutting Analysis of

- Energy, Climate, the Environment, and Sustainable Development. *Environmental Modelling & Software* **2019**, 112, 143–156. <https://doi.org/10.1016/j.envsoft.2018.11.012>.
- (8) Fragkos, P.; Kouvaritakis, N. Model-Based Analysis of Intended Nationally Determined Contributions and 2 °C Pathways for Major Economies. *Energy* **2018**, 160, 965–978. <https://doi.org/10.1016/j.energy.2018.07.030>.
- (9) Baumstark, L.; Bauer, N.; Benke, F.; Bertram, C.; Bi, S.; Gong, C. C.; Dietrich, J. P.; Dirnaichner, A.; Giannousakis, A.; Hilaire, J.; Klein, D.; Koch, J.; Leimbach, M.; Levesque, A.; Madeddu, S.; Malik, A.; Merfort, A.; Merfort, L.; Odenweller, A.; Pehl, M.; Pietzcker, R. C.; Piontek, F.; Rauner, S.; Rodrigues, R.; Rottoli, M.; Schreyer, F.; Schultes, A.; Soergel, B.; Soergel, D.; Strefler, J.; Ueckerdt, F.; Kriegler, E.; Luderer, G. REMIND2.1: Transformation and Innovation Dynamics of the Energy-Economic System within Climate and Sustainability Limits. *Geosci. Model Dev.* **2021**, 14 (10), 6571–6603. <https://doi.org/10.5194/gmd-14-6571-2021>.
- (10) CMCC. WITCH Documentation, 2019. <https://doc.witchmodel.org/>.