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Demand-Side Strategies for CO2 Emission Reductions: An Integrated Assessment Modeling Perspective

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Summary

The decarbonization of energy end-use sectors, such as transportation and buildings, presents a significant challenge for mitigating the impacts of climate change. We conducted a model-intercomparison analysis to assess the potential for reducing CO2 emissions through demand-side strategies. The study focuses on the buildings and transport sectors and evaluates the effectiveness of three strategies: activity shifts, technological improvements, and electrification and fuel shifting. The results demonstrate that the intervention strategies can significantly reduce CO2 emissions. Moreover, combining approaches not only enhances emission reductions, but also alleviates stress on the energy system from individual demand-side changes, such as increased electricity demand.

Introduction

It has become increasingly clear that demand-side mitigation is a critical part of strategies to meet the Paris climate goals (IPCC, 2022; Mundaca et al., 2019). Demand side changes, including lifestyle choices, consumer technology choices, and energy-saving behavior, can aid in mitigating climate change in the short term and reduce the need for carbon dioxide removal technologies in the long term. Reduced energy demand also allows for more flexibility in technology choice in the supply sectors (IPCC, 2022). Also,

electrification of energy end uses can contribute substantially to emission reductions on the demand side and has synergies with the transition to renewables-based power systems (Luderer et al., 2022).

Recent estimates (IPCC, 2022) suggest that shifting and reducing activity, together with improving efficiency in end-use sectors, could potentially lead to sectoral emission reductions of 40-70% by 2050. However, these estimates only consider individual assessments and fail to account for the interactions between various interventions. To overcome this limitation, our study takes a comprehensive approach by employing multiple integrated assessment models (IAMs) to analyze the combined effects of various demand-side intervention strategies in the buildings and transport sectors.

Methods and scenarios

The study uses multiple IAMs (COFFEE, IMACLIM-R, IMAGE, MESSAGE¹, PROMETHEUS, REMIND and WITCH¹) to analyze a set of demand-side intervention scenarios, examining specifically the area of buildings and transport, including personal mobility and international transport. The use of a wide range of models enables the derivations of a robust signal as well as an indication of uncertainty. By gathering input from stakeholders through a survey, we identified a comprehensive list of measures with both high impact and feasibility. Broadly speaking, these measures can be grouped into activity reductions and behavioral shifts, technology improvements and electrification of end-uses. Consequently, we translated them into the following scenarios each representing distinct intervention strategies:

1. **Activity reduction and activity shift (ACT)** *involves redesigning service-provisioning systems to either reduce or shift consumption of services.* People live in smaller spaces, work in shared buildings with flexible use, and adjust their thermostat settings to lower (heating) or higher (cooling) setpoints. Active modes of transportation are encouraged, and public transport and shared mobility options are improved. Air travel is discouraged, while advancements in freight logistics and speed restrictions in maritime transport enable more efficient transport of goods.
2. **Technological improvements - energy efficiency (TEC)** *focuses on improvements in the efficiency of existing technologies.* Higher levels of energy efficiency are achieved in both new constructions and existing buildings through increased renovation rates, improved insulation, and more efficient heating, ventilation, and air conditioning (HVAC) systems. Efficiency standards for road vehicles, aircrafts and ships are implemented and environmental certification is required for using airports and ports.
3. **Electrification and fuel shift (ELE)** *focuses on switching to low-carbon technologies.* Heat pumps and electricity-based heating systems are widely adopted in buildings. Non-clean heating fuels are phased out and new natural gas connections are banned in the Global North. Passenger vehicles, light-duty trucks, and ports transition to full electrification. Heavy-duty vehicles abandon diesel engines, and biofuels and electrofuels are increasingly used in aviation and shipping.
4. **All interventions (ALL)** *combines all of the strategies above.*

While related to the ASI (Avoid-Shift-Improve) framework developed by (Creutzig et al., 2022), our framework allows for a cleaner separation between intervention strategies and related impacts on the energy system and emissions.

¹ Scenario results for MESSAGE and WITCH are not yet available and are not included in the results.

We compare the results to a reference scenario (REF) where none of the above strategies are implemented. The scenario ensemble is further diversified by adding another dimension considering different *climate pathways* that limit (or do not limit) global warming by means of carbon pricing: continuation of current national policies (NPI), and climate policies consistent with 1.5°C global warming targets (1.5C).

Results

In the reference current policy scenario, global emissions from buildings and transport are projected to increase on average with 20 % (16-27%) in 2030 and 34% (26-50%) in 2050 compared to 2015 levels (Figure 1). All intervention strategies acting on top of current policies lead to reduced emission growth in the coming decades compared to the reference. The models project that the current trend of emission growth in the transport and buildings sectors can be reversed into emission reductions when combining all the measures.

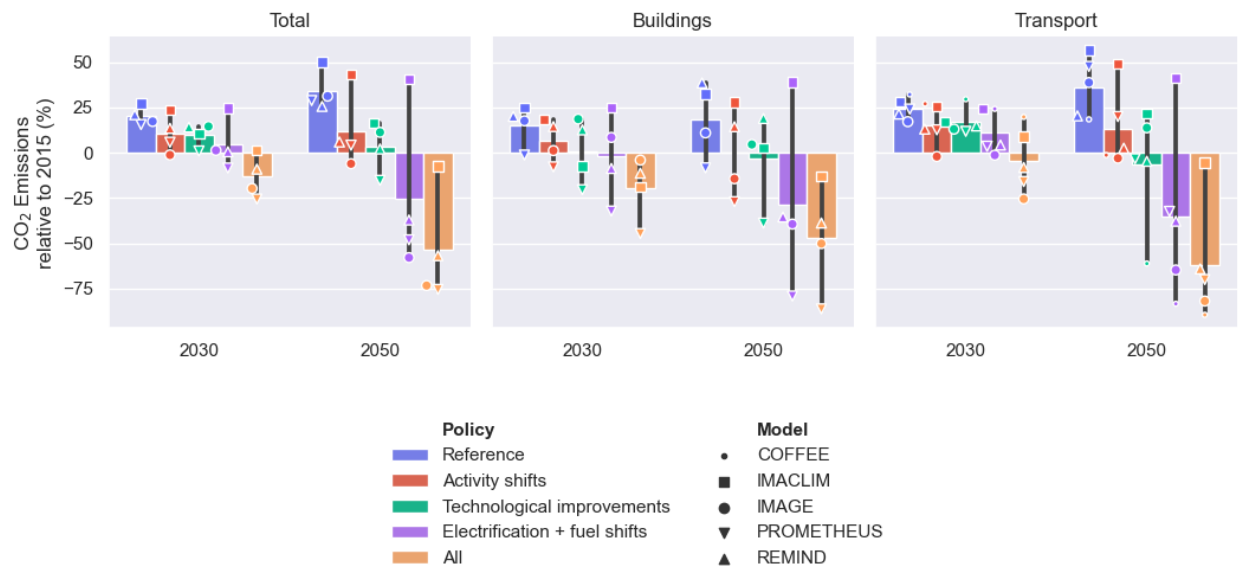


Figure 1: Growth of (direct) CO₂ emissions from fuel combustion in the energy demand sectors in 2030 and 2050 with respect to 2015 in a current policies scenario. The left panel shows the total of the buildings and transport sectors. Bars indicate model-averages and black lines depict the model ranges.

Electrification and fuel shifts can play a pivotal role in reducing demand-side CO₂ emissions in both sectors, but they also result in a substantial surge in electricity demand (Figure 2). Conversely, activity reductions and technological improvements help decrease electricity demand. As a result, the combined intervention scenarios (ALL) exhibit lower electricity demand compared to scenarios focused solely on electrification (ELE), even under a 1.5°C climate target. This implies that a comprehensive approach can reduce the need for emission-reducing technologies, large-scale electricity storage and investments in electricity infrastructure.

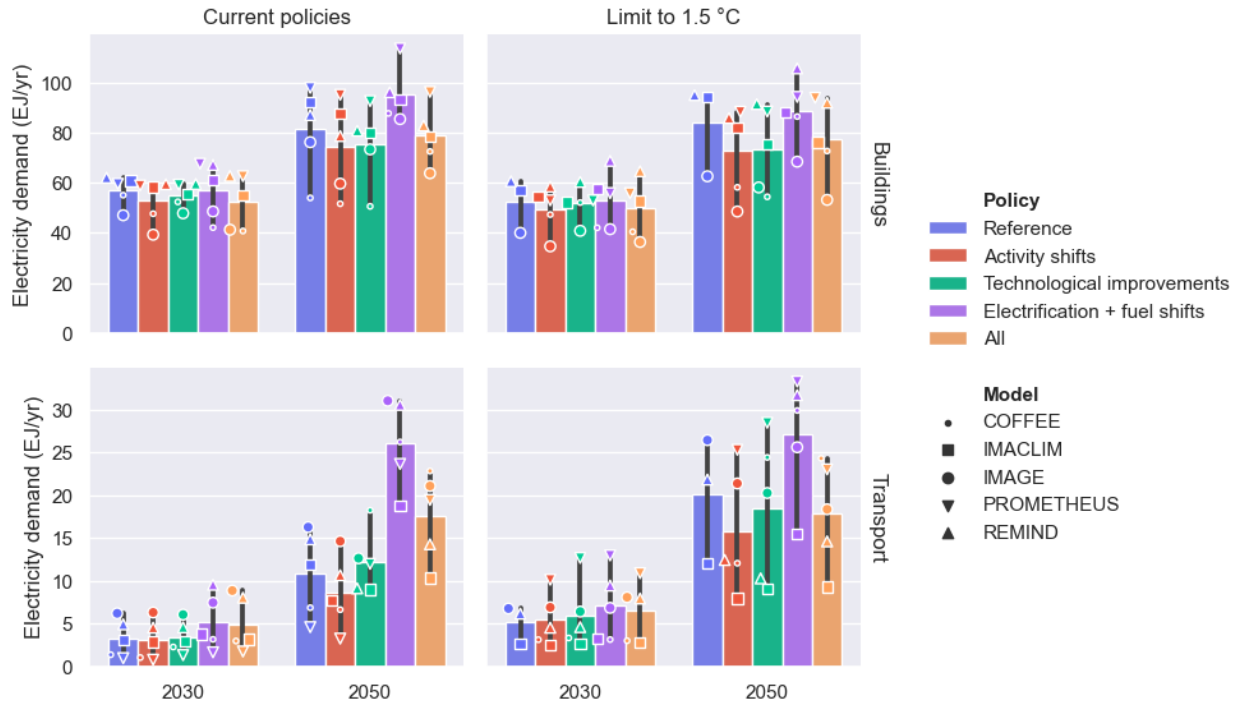


Figure 2: Electricity demand in the energy demand sectors in 2030 and 2050 under two different climate pathways. The left panel shows the total in all energy demand sectors combined (also including industry emissions). Bars indicate model-averages and black lines depict the model ranges.

Our findings highlight the significance of demand-side changes in addressing emissions in the building and transport sectors. Demand-side changes can facilitate the achievement of climate targets and reduce the need for other mitigation measures. Combining different approaches proves particularly advantageous in this context. This approach not only leads to the greatest reduction in emissions but also helps alleviate the stress on the energy system that may arise from individual demand-side changes, such as an increase in electricity demand due to electrification.

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