Comparative Analysis of Decarbonization Strategies for Building Stock: Evaluating Electrification and Alternative Approaches through Multi-Model Scenarios

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Motivation and Research Question

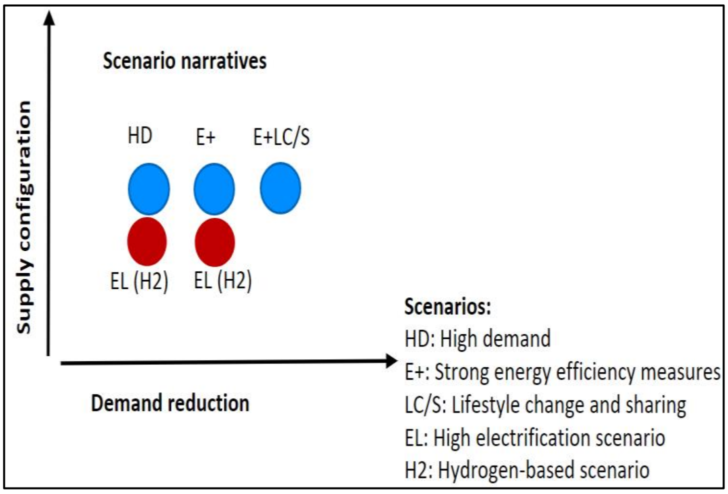
Modeling the potential future scenarios of buildings' energy carrier mix and energy consumption levels plays a crucial role in comprehending and strategizing for decarbonization pathways. It is imperative to compare the results obtained from different models to understand their specific characteristics and ensure unbiased analysis. However, conducting effective model comparisons can be challenging when scenario specifications are not standardized and comparable. In order to address this issue, a comprehensive scenario specification and model run task were undertaken as part of the ECEMF project [1]. This task involved the formulation of seven distinct scenarios, designed to represent a spectrum of high and low demand levels and different technology focuses. To assess the outcomes of these scenarios, multiple building stock models, namely Invert/EELab [2], Invert/Opt [2], FORECAST-Buildings [3], PRIMES-Buildings [4], and REMIND-Buildings [5], were employed to simulate the various scenarios. By conducting this comparative analysis across multiple models, a more robust understanding of the potential decarbonization pathways of the building sector can be achieved. Furthermore, the primary objective of this study was to analyze and evaluate the different options available for decarbonizing the energy demand in buildings, specifically focusing on the comparison between electrification and other potential strategies.

The paper deals with the following research questions: What are the key factors contributing to the disparities observed among the various models in decarbonization scenarios of the EU building sector? Furthermore, what are the shared insights and reliable findings that emerge across the range of scenarios examined?

Methodology

As an initial step, we established the scenario narratives. A set of seven scenarios was created, aiming to capture different levels of demand reduction while considering diverse supply configurations:

1. High Electrification|Efficiency Moderate
2. High Electrification|Efficiency High
3. High Electrification|Lifestyle and Behavioral Change
4. High H2/e-fuels|Efficiency Moderate
5. High H2/e-fuels|Efficiency High
6. High District Heating|Efficiency Moderate
7. High District Heating|Efficiency High



As previously elucidated, this study incorporates five distinct building stock models. Invert/EELab is a techno-socio-economic bottom-up simulation model that employs a logit approach, representing building owners as agents with distinct decision-making parameters [2]. Invert/Opt, on the other hand, is an economic bottom-up optimization model that seeks to derive the most cost-effective combination of renovation measures and technology choices for a specified target year [2]. FORECAST-Buildings, a bottom-up simulation model, takes into account the dynamics of technologies and socioeconomic drivers to project future energy demand in the buildings sector [3]. PRIMES-Buildings, a hybrid economic-engineering optimization model, is grounded in microeconomic theory and endeavors to capture consumer behaviors while incorporating engineering constraints [4]. Lastly, REMIND-Buildings integrates an energy-economy general equilibrium model with a bottom-up engineering-based energy system model.

The complete conference contribution will provide in-depth fundamental information regarding the modeling structure, algorithms, and other pertinent details for each model, including a comparative analysis of the models' approaches. Furthermore, comprehensive reporting will be conducted on the general scenario specifications and internal assumptions for each model. To ensure uniformity in data formats, definitions, and structure, the results have been uploaded to IIASA's Scenario Explorer tool [6], facilitating the necessary visualizations. In the results section, the outcomes of the comprehensive analysis will be presented and scrutinized for each scenario and model, enabling the identification of variations within scenarios as well as across different models. Subsequently, an extensive examination of these results will be undertaken to clarify the potential factors responsible for these observed deviations. Particularly, emphasis will be placed on comparing the effectiveness of electrification against alternative approaches in the context of decarbonizing building stock.

Results

We will deliver the results in terms of:

1. Total final energy consumption in the residential and commercial sectors,
2. Total final energy consumption by energy carriers in the residential and commercial sectors,
3. Total final energy consumption by end-use in the residential and commercial sectors.

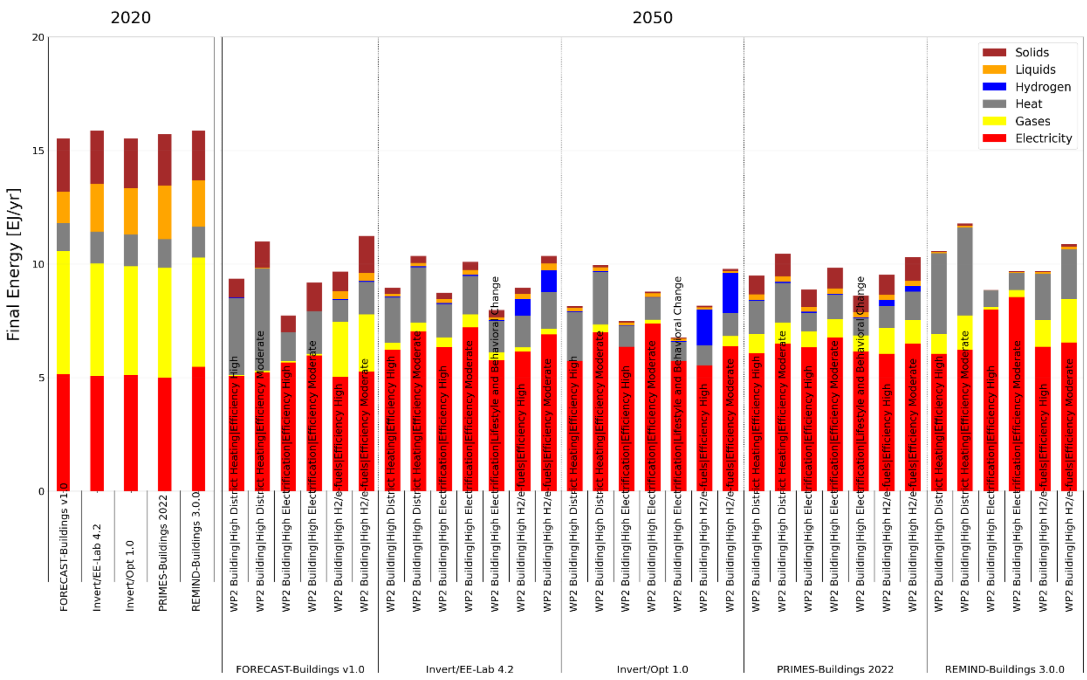


Figure 1 Energy carrier demand by energy carrier in buildings in 2020 and 2050 in different scenarios and models (EU27)

Figure 1 provides a visual representation of the final energy consumption with the energy carrier mix within the building sector for each model and scenario, specifically focusing on the year 2050. It is worth noting that when considering the absolute magnitude of energy demand within this sector in the baseline year of 2020 (measured at 15.47 EJ), the overall deviations observed between the models are deemed to be of a moderate nature [7]. However, notable disparities become more pronounced, particularly between the high and moderate scenarios, as exemplified by the contrast between the Forecast and Primes models. These variations underscore the significance of scenario specifications and modeling approaches in influencing the energy demand in the building sector.

Figure 2 presents the distribution of direct electrification shares across the EU27 region, as assessed with each scenario and model. Additionally, in Figure 3, the installed capacity of heat pumps is provided. The outcomes demonstrate a wide-ranging spectrum of direct electrification, spanning from 43% to 90% in 2050. Notably, the REMIND model emerges with the highest levels of electrification as a result of both the prominent utilization of heat pump technologies and the high demand for appliances. Differences in electrification shares do not only result in different assumptions of heat pump penetration but also in technology settings for competing technologies such as biomass-based heating systems or district heating. Also, the share of appliances in total energy demand and – related to it – the achieved energy savings through building renovation have an impact on the share of electrification in this sector. These findings provide valuable insights into the slight variations observed in the degree of direct electrification across different scenarios and models, which hold substantial importance for policymakers and stakeholders engaged in decision-making about the imperative transition towards sustainable energy systems. By comprehensively evaluating these outcomes, this study contributes to the body of knowledge essential for shaping effective strategies and policies in achieving sustainable and decarbonized building energy systems. Reasons for these deviations include different model dynamics and also differences in the detailed scenarios specifications.

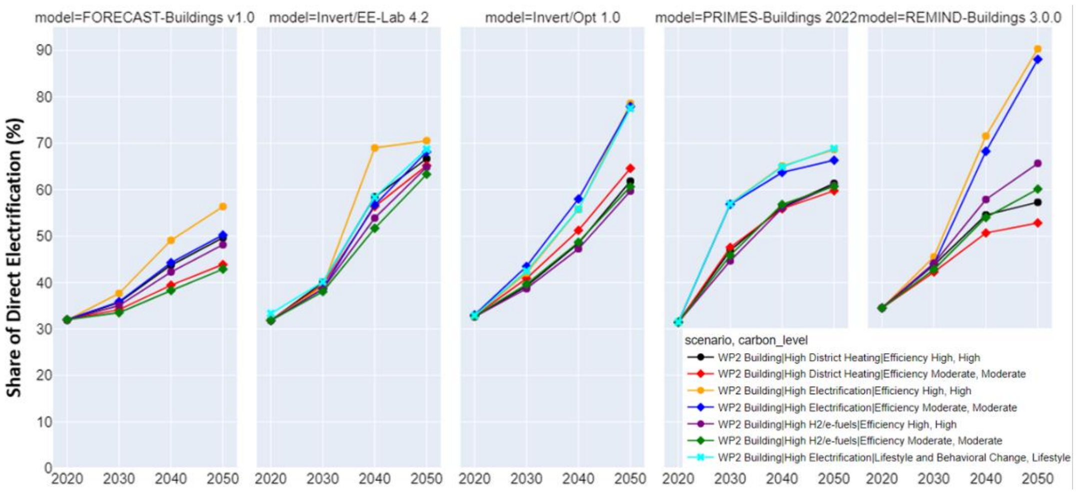


Figure 2 Share of direct electrification in buildings' final energy consumption, 2020 - 2050 (EU27)

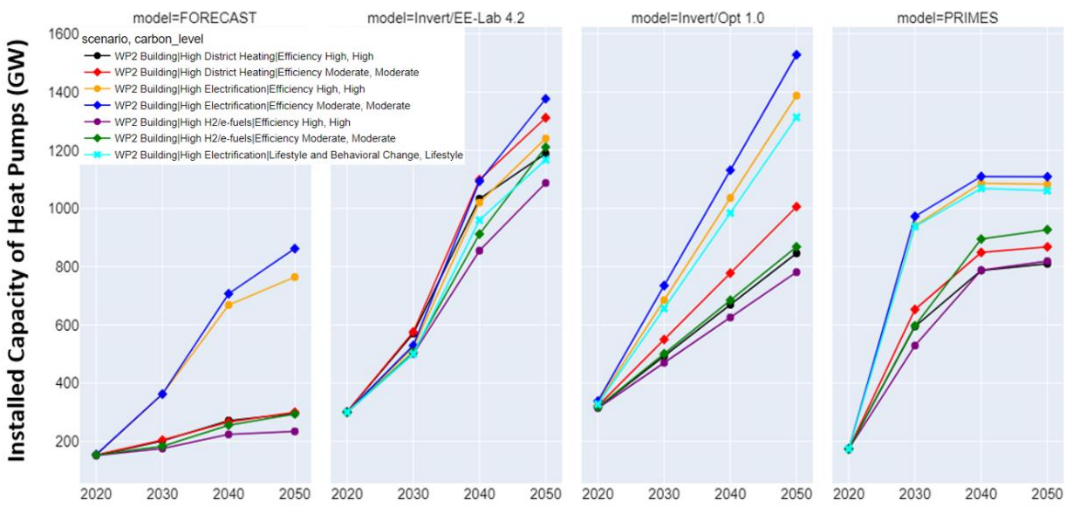


Figure 3 Installed capacity of heat pumps in the residential and commercial sector, 2020 – 2050 (EU27)

The following key learnings can be derived as common learning from all models: (1) Substantial enhancement of building renovation and related improvement of the building envelope is key for a decarbonised building stock. (2) Heat pumps play a crucial role in the heating system mix of all scenarios, even in scenarios with a focus on other technologies such as H2 and e-fuels or district heating. (3) H2 and e-fuels do not turn out to be an efficient and economically viable solution in any of the models, not even in the dedicated H2/e-fuels scenarios. (4) District heating is important for decarbonisation, but models lead to different intensities of district heating expansion. In the full paper, we will further expand on these insights and also discuss the reasons for deviations.

References

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