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Forecasting Urban Residential Stock Turnover Dynamics using System Dynamics and Bayesian Model Averaging

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The global building sector is critical to meeting global climate goals, but is currently off-track from Paris-compliant pathways such as that laid out in the IEA's Sustainable Development Scenario. In particular, building floor area has a direct impact on the acceleration of building energy intensity reduction needed to bring buildings on track. As a major driving force of global building sector growth, the floor area of new buildings constructed in China in 2018 was 2.5 billion m^2, accounting for 34% of the global new buildings. In 2018, energy consumption by Chinese buildings was 504 million tons of oil equivalent (mtoe). China's share in global building energy consumption increased from 13% in 2010 to 16% in 2018. More than one third of building energy in China was consumed by urban residential buildings. With growing urban population and higher demand for energy services in the built environment, urban residential buildings will have increasing importance in China's efforts in decarbonising its building sector. However, official statistics on total floor area of urban residential buildings in China only exist up to 2006. The historical growth trajectory of the stock from 2007 onwards is therefore unknown. This lack of authoritative data creates a key barrier to forecasting future trajectories of urban residential stock and analysing stock-level energy consumption.

We present a modelling approach to estimate recent historical total stock of urban residential buildings in China and also to forecasting future trajectories of the stock evolution. A disaggregated build stock model is developed using System Dynamics to characterise the building aging process and stock turnover dynamics. This model is then operationalised by separately investigating five candidate parametric survival models to represent the uncertainties associated with building lifetime. With each survival model, the stock turnover is simulated through Markov Chain Monte Carlo methods to obtain the posterior predictive distribution of total historical stock and the marginal likelihood used to estimate the posterior model probability. Bayesian Model Averaging is applied to create a model ensemble to combine model-specific predictions of the historical stock evolution pathway based on model probabilities. By extending the model structure and incorporating variables relating to possible trends in urbanisation and demand for per capita floor area, future stock turnover dynamics through 2100 are forecasted and then combined through model averaging. In so doing, we can obtain not only forecasts of total stock, age-specific substocks, annual new construction and annual demolition, but also their posterior predictive distributions which fully characterise their uncertainties.

Our modelling results suggest that the total stock would increase gradually through to 2065 when it reaches the peak, at which point the mean of its distribution is 46.3 billion m^2 and the 95% confidence interval ranges from 42.4 to 50.1 billion m^2. Beyond 2065, the total stock decreases slowly as a result of the combined effect of projected decrease of total population around the same period and the continuous but decelerating increase in urbanisation rate and per capita floor area. The level of total stock by 2100 is approximately 3 billion m^2 below the peak level in 2065. Future annual new buildings are not expected to vary significantly from the recent historic levels. Its mean value increases to around 1.5 billion m^2, remains generally stable for two decades and then starts to slowly decrease to 1 billion m^2 by 2100. The annual demolition rate shows a slowly ascending pattern that starts to plateau around 2050, after which it remains in the range of 1.1 to 1.2 billion m^2. The predictive distributions of all these variables of interest reflect the uncertainties associated with the parameters of the Logistic model for urbanisation, the parameters of the Gompertz model for per capita floor area, the parameters of each of the five survival models for lifetime distribution and demolition probability, and the survival models themselves

In summary, our study offers a first-of-a-kind analysis that employs a Bayesian approach to investigate the uncertainties associated with modelling Chinese building stock, which is a policy relevant but under-researched area. The modelling approach adopted here is well suited to carry out studies of stock-level energy and carbon impacts. In particular, the model's ability to explicitly track the aging process of substocks and fully represent probability distributions at both the stock and substock level is critical to analysing the policy trade-offs facing Chinese residential buildings regarding embodied versus operational energy consumption and carbon emissions in the context of sector-wide decarbonisation. Beyond the present study, which is aimed at assessing the Chinese building stock, the generality and flexibility of the modelling approach suggests its wider applicability in other geographical contexts.

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