

Urban renewal liabilities from ageing housing cohorts

Yang Zhou

zhouyang2021@ruc.edu.cn

Renmin University of China

Yu Chen

Renmin University of China

Jinming Yan

Renmin University of China

Yumeng Li

Renmin University of China

Qi Zhang

University of North Carolina at Chapel Hill <https://orcid.org/0000-0002-4242-7614>

Article

Keywords:

Posted Date: August 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10523302/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: There is **NO** Competing Interest.

Urban renewal liabilities from ageing housing cohorts

Yu Chen¹, Jinming Yan^{1*}, Yumeng Li¹, Qi Zhang², Yang Zhou^{3*}

1 School of Public Administration and Policy, Renmin University of China, Beijing, China

2 Department of Geography and Environment, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

3 School of Agricultural Economics and Rural Development, Renmin University of China, Beijing, China

**E-mail: yanjinming@ruc.edu.cn; zhouyang2021@ruc.edu.cn*

Construction booms can create delayed urban liabilities when large housing cohorts age together. Using building-level records for 1.53 million residential buildings in Quanzhou, China, we develop a policy-calibrated framework that maps renewal priority, projects cohort ageing to 2050 and separates pathway-specific fiscal and carbon exposure. The 2020 policy anchor identifies 521,235 buildings (34%) above the renewal-pressure threshold; about 531,000 (35%) are identified by 2050, indicating that most pressure is inherited rather than newly emerging. Demolition of the cumulative stock implies 364–571 billion RMB (\$53–84 billion) in compensation exposure and 968.4–974.5 ktCO₂ of one-off emissions. In situ renewal requires 7.6–19.0 billion RMB (\$1.12–28.05 billion) in direct investment, while retained buildings carry 2.56–2.60 MtCO₂ yr⁻¹ in baseline operational emissions. These non-equivalent accounts reveal how past construction waves constrain future renewal finance and decarbonization.

Urbanization creates obligations that persist long after construction ends. Over recent decades, rapid urban growth has produced vast residential stocks whose maintenance and governance consequences emerge only as the buildings age^{1–3}. When construction is concentrated in a few boom periods, many buildings can approach functional obsolescence within the same planning horizon. Cities must then coordinate repair, retrofit, replacement, resident relocation and infrastructure upgrading at a scale that differs from the incremental redevelopment typical of mature housing systems^{4–6}. The physical legacy of expansion can therefore become a delayed fiscal, social and environmental liability.

Most urban-renewal research explains redevelopment through neighbourhood decline, rent gaps, land-value change, market incentives and policy intervention^{7–9}. Studies of Chinese cities have added important evidence on institutional innovation, land redevelopment and the regulatory role of the state^{10–13}. This literature is strongest at explaining why particular sites or projects are renewed, how redevelopment is negotiated and where activity is concentrated. It is less well equipped to explain a city-wide temporal problem: why renewal pressure can accumulate across an entire housing system decades after a construction boom.

A housing-stock perspective shifts attention from individual projects to the age structure of the built environment. Buildings are produced in cohorts under different technical standards, material regimes, land institutions and demographic conditions. Research on urban material stocks shows that construction, accumulation and replacement unfold in waves, with long-delayed consequences for resource demand, urban form and infrastructure governance^{4,14,15}. Where housing production is temporally concentrated, cohort ageing can synchronize the entry of many buildings into a period of elevated renewal need¹⁶. Past construction geography may thus preconfigure both the timing and the spatial distribution of future renewal.

Three unresolved issues limit this stock-based account. First, ageing alone does not determine renewal priority: structural condition interacts with accessibility, redevelopment potential, population concentration

and social vulnerability^{17–20}. Second, few building-level studies project how priority changes when a fixed classification rule is anchored to an observed policy baseline rather than selected arbitrarily. Third, pathway choice creates different fiscal and carbon accounts. Demolition activates compensation, relocation and one-off construction-stage emissions, whereas retention and retrofit require direct investment and leave a recurring operational-energy burden. These accounts operate over different time scales and should not be collapsed into a single, unqualified comparison.

China offers a revealing setting for examining these issues. Four decades of expansion-led urbanization generated large residential stocks, while national policy now emphasizes stock improvement, urban renewal and more efficient use of existing assets²¹. This transition from land expansion to the management of accumulated buildings is not unique to China, but its scale is unusually visible there. Housing that enabled rapid growth is becoming a long-term governance obligation, testing local fiscal capacity, planning coordination and the compatibility of renewal with decarbonization.

The Chinese case also broadens the geography of urban renewal. Residential construction has occurred across formal urban districts, county seats, peri-urban corridors and extensive rural settlements^{1,23}. These components are embedded in a dual urban–rural land system and are governed through different tenure, compensation and implementation arrangements^{23–25}. Rural settlement change is therefore not peripheral to metropolitan transformation. A building-stock analysis must compare these spaces without treating a diagnostic threshold derived from urban policy as evidence that rural buildings are formally enrolled in the same programme.

Here we analyse 1,527,878 residential buildings across Quanzhou, a rapidly urbanizing coastal city in southeastern China (Supplementary Fig. 1). We develop a building-level P4 framework—Priority, Projection, Pressure and Pathways—to identify spatial renewal priority, project the ageing of the 2020 stock to 2050, quantify the buildings, dwelling units, floor area and land involved, and estimate pathway-specific fiscal and carbon exposure (Fig. 1 and Supplementary Fig. 2). The nine-indicator Comprehensive Urban Renewal Priority Index (CPI) combines physical, locational and demographic information (Supplementary Tables 1–3). Its fixed threshold is calibrated to the 56,000-household scale documented for Quanzhou’s 2020 municipal old residential community renovation programme²².

The analysis yields three linked insights. Renewal pressure is organized by construction cohorts rather than distributed randomly; it extends across the wider metropolitan settlement system rather than remaining an inner-city phenomenon; and most of the mid-century pressure is already embedded in the 2020 housing stock. Pathway analysis further shows that demolition and in situ renewal do not simply differ in magnitude: they activate different fiscal instruments and different carbon time scales. Urban renewal is therefore better understood as anticipatory management of a long-lived housing system than as a succession of isolated redevelopment projects.

Results

Construction booms left distinct housing cohorts

Quanzhou’s residential stock records successive construction waves since the 1980s, with the largest expansion occurring during 2001–2010 (Fig. 2a, d). Earlier cohorts cluster in historical urban cores,

established towns and long-standing rural settlements, whereas later cohorts extend along urban districts, development corridors and peri-urban settlement belts. The resulting landscape is not a uniformly ageing city but a spatial mosaic of cohorts produced at different stages of urbanization (Supplementary Figs. 1 and 3 and Supplementary Table 4).

Building form and construction material reinforce this cohort structure. Multi-storey and high-rise housing is concentrated in urban districts, while rural settlements remain dominated by low-rise buildings (Fig. 2b). Reinforced concrete progressively displaced traditional materials and became the dominant structure in urban residential construction by 2020 (Fig. 2c). From the 1980s to 2020, the mean height of urban residential buildings increased from 5.33 to 13.72 m and the mean number of storeys from 1.73 to 4.45 (Supplementary Figs. 3 and 4 and Supplementary Tables 4 and 5).

The later construction waves were also markedly more vertical. The mean number of storeys in newly built urban housing rose from 2.55 in the 1980s to 8.59 in the 2010s (Fig. 2e), while the reinforced-concrete share increased from 3.36% in 1980 to 61.9% in 2020 and timber structures became marginal (Fig. 2f). These shifts matter for renewal because building count alone understates the households and floor area concentrated in newer urban cohorts. Quanzhou's future renewal profile is therefore shaped jointly by when buildings were constructed, where they are located and the forms in which successive cohorts were built (Supplementary Figs. 4–7 and Supplementary Tables 4 and 5).

Renewal priority spans the metropolitan settlement system

The three components of renewal priority have distinct geographies. The physical index concentrates older and structurally vulnerable buildings in historical urban areas, established towns and long-standing rural settlements (Fig. 3a). The economic index is highest near urban centres, commercial land, public services and transport corridors (Fig. 3b). The social-need index highlights places where population concentration, population ageing and limited residential space increase the potential consequences of building decline (Fig. 3c and Supplementary Fig. 2 and Supplementary Table 1).

We integrate these dimensions in a Comprehensive Urban Renewal Priority Index (CPI), where higher values indicate a stronger combination of physical, locational and social priority (Fig. 3d). To avoid an arbitrary cutoff, we rank urban residential buildings by CPI and identify the point at which cumulative dwelling units reach the 56,000-household scale of Quanzhou's 2020 renovation programme. This policy anchor produces a fixed threshold of 0.42, corresponding to 56,009 urban dwelling units at the cutoff. The same threshold is retained throughout the 2020–2050 analysis (Fig. 3e, f and Supplementary Tables 1 and 6).

Buildings above the threshold form compact urban hotspots around municipal and county centres and a much broader, more dispersed pattern across peri-urban and rural settlements (Fig. 3e, f). In 2020, approximately 0.52 million buildings exceed the threshold, of which nearly 0.50 million are rural buildings (Fig. 3g and Supplementary Table 6). This asymmetry reflects the numerical dominance of low-rise rural structures and should not be interpreted as formal inclusion in an urban renovation programme. The urban subset represents demand calibrated to an observed urban-policy scale; the rural subset is a comparable diagnostic of latent settlement-improvement pressure under the same index rule. The result nevertheless shows that the housing-stock ageing is metropolitan in extent, not confined to the historic core.

Most future pressure is already embedded in the 2020 stock

Projected renewal-priority hotspots expand from existing clusters rather than emerging in unrelated locations (Fig. 4a). Municipal and county centres, transport corridors and peri-urban settlement belts remain the dominant concentrations through 2050. This persistence indicates that future pressure is strongly path dependent: the geography of past construction continues to organize where ageing buildings, residents and floor area accumulate (Supplementary Table 6-10).

The most striking temporal result is the dominance of the baseline stock. In 2020, 521,235 buildings already lie above the policy-calibrated threshold—about 98.1% of the 2050 total. Subsequent five-year additions are small and gradually decline across demographic scenarios, from 1,810–1,812 buildings in 2025 to 1,506–1,514 in 2050 (Fig. 4b). Quanzhou therefore faces less a rapidly arriving future wave than a large inherited obligation that is already present, followed by a slower stream of cohort entrants (Supplementary Tables 6–8).

Urban and rural increments differ in both number and implementation meaning (Fig. 4c). Rural buildings account for most new structures crossing the threshold in each interval, whereas the smaller urban increment is associated with denser occupation and larger concentrations of dwelling units and floor area. By 2050, 531,066–531,081 buildings, 579,047–579,988 dwelling units and 162.1–162.3 million m² of floor area are projected to exceed the threshold. Planning must therefore distinguish a compact urban burden measured strongly in households and floor area from a dispersed rural burden measured strongly in building count and territorial reach (Supplementary Tables 7, 9 and 10).

Renewal pathways activate different fiscal and carbon accounts

Applying demolition and in situ renewal scenarios to the same priority stock reveals two different forms of exposure (Figs. 5 and 6). Under demolition, the fiscal account is compensation and the carbon account is a one-off release during removal. Under in situ renewal, the fiscal account is direct retrofit investment and the carbon account is the annual operational emissions of the retained stock. These quantities are intentionally

reported separately: compensation and engineering investment are not equivalent cost concepts, and demolition-stage and operational emissions are not equivalent time-integrated carbon measures (Supplementary Tables 11–15).

Fiscal exposure is strongly concentrated around municipal and county centres in 2020. Higher local compensation benchmarks and larger amounts of affected floor area produce demolition-compensation hotspots in these locations (Fig. 5a). Direct in situ renewal investment is substantially smaller and follows the distribution of floor area above the threshold, although it remains spatially concentrated where the priority stock is largest (Fig. 5b and Supplementary Table 6).

For cohorts newly crossing the threshold, lower-bound demolition compensation ranges from 5.8 to 22.2 billion RMB per five-year interval and upper-bound compensation from 6.9 to 25.0 billion RMB (Fig. 5c). Direct in situ renewal investment ranges from 0.04 to 0.12 billion RMB under the low-cost setting and from 0.09 to 0.29 billion RMB under the high-cost setting (Fig. 5d). Across the cumulative priority stock in 2050, compensation exposure reaches 363.6–571.3 billion RMB, compared with 7.6–19.0 billion RMB in direct retrofit investment. The implied scale contrast ranges from 19.2 to 75.2, but it is an exposure ratio rather than a full life-cycle cost–benefit comparison because the two pathways include different expenditure components (Supplementary Tables 11–13).

The carbon results operate on two clocks. Demolition of the 2020 priority stock would release carbon once during the removal stage (Fig. 6a), whereas retention leaves an annual operational emissions baseline that persists unless retrofit measures reduce energy demand or the energy system decarbonizes (Fig. 6b). The maps therefore identify where each pathway activates carbon-management needs rather than establishing a single ranking of total life-cycle emissions (Supplementary Tables 6 and 14).

For buildings newly crossing the threshold, demolition-stage emissions range from 14.8 to 64.4 kt CO₂ per five-year interval, while baseline operational exposure ranges from 38.5 to 103.2 kt CO₂ yr⁻¹ (Fig. 6c). Urban buildings dominate both accounts: they contribute 13.1–62.6 kt CO₂ of demolition emissions compared with 1.5–1.8 kt CO₂ for rural buildings, and 28.5–75.1 kt CO₂ yr⁻¹ of operational emissions compared with 3.1–28.1 kt CO₂ yr⁻¹ for rural buildings (Fig. 6d). Urban density therefore converts a relatively small building count into a disproportionately large carbon exposure (Supplementary Table 14).

By 2050, full demolition of the cumulative priority stock implies 968.4–974.5 kt CO₂ of demolition-stage emissions, whereas retained buildings carry 2.56–2.60 Mt CO₂ yr⁻¹ in baseline operational emissions. These values should not be added or compared as if they shared a common time horizon. Their significance is institutional: demolition requires management of a concentrated emissions pulse, while in situ renewal makes

retrofit depth, household energy demand and energy-system decarbonization central to long-term performance. Housing-stock ageing thus connects renewal finance to carbon governance without reducing pathway choice to a single headline metric.

Discussion

Construction booms create delayed renewal liabilities

The central finding is that renewal pressure is partly predetermined by the generational structure of the housing stock. Successive waves of construction produced cohorts that differ in age, material, height, settlement context and occupancy intensity. As these cohorts age, renewal priority becomes spatially clustered and temporally coupled. The geography of future intervention is therefore inherited, in part, from the geography of past urban expansion.

This interpretation extends project-centred accounts of urban renewal. Neighbourhood decline, land values, governance arrangements and market incentives remain essential for explaining which projects proceed and whose interests prevail^{7,9,10}. They do not, however, fully explain why many sites can become candidates for intervention within the same period. Building-cohort composition supplies that missing temporal mechanism: concentrated production creates concentrated ageing, even before a specific redevelopment decision is made²⁶.

The result also connects urban renewal to material-stock research²⁷. Long-lived built assets store not only materials and embodied carbon but also deferred maintenance, adaptation and replacement obligations^{4,14,15}. A construction boom can therefore be understood as creating a future renewal liability. This liability is not a deterministic prediction that every building will be redeveloped; it is a structured exposure that narrows future choices and increases the need for planning, finance and technical capacity²⁸.

Renewal pressure is metropolitan rather than inner city

Quanzhou's priority landscape extends across urban cores, county seats, peri-urban corridors and rural settlements. This finding challenges the common spatial shorthand that equates urban renewal with inner-city redevelopment^{32–34}. In rapidly urbanizing regions, the relevant unit is often the wider metropolitan settlement system, because urban construction, rural housing expansion, mobility and service networks have co-evolved across administrative and tenure boundaries^{1,29}.

The urban–rural asymmetry is substantive rather than merely cartographic. Urban buildings are fewer but taller, more densely occupied and more consequential in terms of dwelling units, floor area, compensation and emissions. Rural buildings are individually smaller but numerically dominant and territorially

dispersed^{30,31}. A single building count therefore obscures two different implementation problems: intensive intervention in compact urban neighbourhoods and extensive coordination across dispersed rural settlements.

China's dual land system sharpens this distinction^{23,24}. Urban renewal involves formal property markets, multi-owner negotiation and municipal compensation rules, whereas rural renewal is conditioned by homestead rights, household construction and village governance. The common CPI threshold is useful for diagnostic comparability, not for policy equivalence. A metropolitan stock strategy should therefore share monitoring standards while differentiating tenure rules, resident participation, service objectives and acceptable intervention pathways³⁵.

Pathway choice separates fiscal and carbon clocks

The pathway analysis reframes renewal as a problem of institutional sequencing. Demolition activates a large, spatially concentrated compensation obligation and a short-duration emissions pulse. In situ renewal requires much less direct engineering investment but leaves a recurring operational-carbon account whose trajectory depends on retrofit depth, occupancy behaviour and energy supply. The two pathways therefore place pressure on different budgets, agencies and time horizons.

This distinction also prevents two common overinterpretations. First, compensation exposure is not the full social cost of demolition, and retrofit investment is not the full life-cycle cost of retention. Second, demolition-stage emissions cannot be directly ranked against one year of operational emissions. A complete pathway appraisal would also include replacement construction, material reuse, relocation, disruption, maintenance, avoided energy use and a common assessment horizon. The present analysis instead identifies the scale and geography of the accounts that policy must manage.

The large 2020 baseline makes delay consequential. Project-by-project redevelopment can respond to the most visible sites, but it cannot by itself coordinate a housing system in which many buildings already exceed a policy-calibrated priority threshold. Anticipatory governance requires building-stock observatories, rolling priority maps, dedicated renewal funds, resident-centred decision processes and coordinated standards for safety, accessibility and energy performance^{5,11,25,36–41}. It also requires explicit triage among maintenance, deep retrofit, adaptive reuse and demolition rather than treating clearance as the default endpoint.

From project renewal to anticipatory stock governance

The quantitative estimates are specific to Quanzhou, but the cohort mechanism has wider relevance. Many cities in Asia, Africa and Latin America continue to add housing through concentrated construction waves and peri-urban expansion. These investments are normally evaluated through immediate supply, affordability

and economic growth. The analysis here suggests a complementary test: whether present construction patterns create synchronized maintenance and renewal obligations that local institutions will be able to finance and decarbonize decades later.

The practical implication is to govern the stock before ageing becomes a crisis. Cities can maintain longitudinal building registers, earmark renewal reserves, phase retrofit programmes by cohort, protect vulnerable residents from displacement, and align renovation standards with operational-decarbonization targets. New construction policy can also reduce future synchronization by improving durability, adaptability and maintainability. Such measures convert renewal from an episodic response to deterioration into a continuous form of urban asset management.

Comparative research is now needed to test how land tenure, housing markets, compensation institutions, demographic change and energy systems mediate cohort-driven renewal. The transferable claim is not that other cities will reproduce Quanzhou's building counts or cost ratios, but that temporally concentrated construction can generate temporally concentrated liabilities. The legacy of rapid urbanization is therefore not only the city already built; it is also the set of fiscal, social and carbon choices that the housing stock carries into the future.

Methods

Study setting and data integration

Quanzhou is a rapidly urbanizing coastal city in southeastern China whose administrative territory includes dense urban districts, county-level centres, peri-urban development corridors and extensive rural settlements. This heterogeneous settlement system provides a useful setting for tracing how housing-cohort ageing translates into spatial priority, future renewal exposure and pathway-specific fiscal and carbon accounts (Supplementary Fig. 1).

We constructed a harmonized building-level geospatial database from four groups of data: administrative boundaries; residential-building records; land-use, facility and road data; and demographic statistics. Building records were derived primarily from the First National Survey of Comprehensive Natural Disaster Risk and include construction year, structural type, number of storeys, dwelling units, floor area and land occupation. Land-use and accessibility variables were compiled from the Second and Third National Land Surveys and annual land-use change surveys. Village population and age structure were obtained from the Seventh National Population Census. Total and older populations were allocated from villages to buildings in proportion to residential floor area, preserving the published village totals and generating building-level estimates of population, older population and per-capita residential floor area (Supplementary Tables 1–3).

All spatial layers were projected to a common coordinate system and subjected to topology correction, duplicate removal, attribute cleaning and spatial matching. Buildings with invalid geometry or irrecoverably missing essential attributes were excluded; correctable records were repaired using the standardized procedures reported in the Supplementary Information. The final database contains more than 1.5 million residential buildings across Quanzhou. Urban and rural classifications follow land-tenure context and the spatial delineation used in the underlying land and building records (Supplementary Figs. 1 and 3 and Supplementary Tables 4 and 5).

P4 analytical design

The P4 framework links four modules (Fig. 1 and Supplementary Fig. 2). Priority estimates the relative need for attention from physical, locational and social indicators. Projection updates the 2020 stock under building-ageing and demographic scenarios. Pressure converts priority into the number of buildings, dwelling units, floor area and land area involved. Pathways estimates the fiscal and carbon accounts activated by demolition and in situ renewal. The modules are connected by a single policy-calibrated CPI threshold that is fixed across years.

The framework estimates latent priority and scenario-based exposure; it does not estimate the probability or date of an actual redevelopment project. Realized intervention depends on resident preferences, ownership, heritage value, engineering assessment, land institutions, market conditions, fiscal capacity and political decisions. The term ‘renewal pressure’ therefore denotes buildings above the diagnostic threshold, not buildings judged unsafe or mandated for demolition.

Building-level renewal priority

We constructed the CPI from nine indicators grouped into physical potential, economic potential and social need. Physical potential includes construction age, structural type and number of storeys. Economic potential measures distance to commercial land, public facilities and road networks. Social need includes allocated total population, allocated older population and per-capita residential floor area. Indicator direction was set so that larger standardized values consistently represent higher renewal priority (Supplementary Fig. 2 and Supplementary Tables 1 and 2).

Each indicator was standardized by min–max normalization using minima and maxima fixed to the 2020 baseline stock. Within each dimension, entropy-derived relative weights were normalized to sum to one and then multiplied by one-third; the final nine indicator weights therefore sum to one, while the physical, economic and social dimensions each contribute one-third to the CPI. The CPI is the sum of these three

weighted dimension contributions. We calibrated the classification threshold externally rather than selecting a quantile or natural-break class. Urban buildings were ranked by CPI until cumulative dwelling units first reached the 56,000-household policy anchor, yielding a fixed threshold of 0.41681972 and 56,009 urban dwelling units at the cutoff. The threshold was then held constant for all years and applied to both urban and rural buildings, subject to the distinct policy interpretations described above (Supplementary Tables 1, 2 and 6).

Calibration was performed only in the urban reference pool because the policy anchor concerns a formal urban programme. The threshold was then applied to urban and rural buildings in 2020 and in all projection years to preserve one diagnostic rule across the housing stock. Urban estimates can be interpreted as policy-calibrated renewal demand. Rural estimates indicate latent settlement-improvement priority under the same index rule; they do not imply programme eligibility, physical failure or compulsory redevelopment (Supplementary Table 6).

Projection of cohort ageing and demographic change

We projected the existing 2020 residential stock annually from 2025 to 2050. The number of buildings was held constant so that the analysis isolates pressure generated by ageing and demographic restructuring within the observed stock. Future construction, demolition and conversion were not added to the baseline; the projections are therefore conditional stock-ageing scenarios rather than forecasts of the complete future built environment.

Building age was updated from construction year in each projection year. Structural type, storeys and locational-accessibility indicators were held constant. These assumptions isolate cohort ageing and avoid introducing unsupported forecasts of infrastructure expansion, land-use change, structural upgrading or redevelopment behaviour.

Village populations were projected with a cohort-component model by sex and five-year age group from the 2020 census baseline. Low-, medium- and high-population scenarios represent alternative fertility trajectories. Age-specific survival probabilities improve gradually over time, and net migration—estimated from recent population change—converges towards zero by 2050. Full parameter values and scenario assumptions are reported in Supplementary Table 3.

For each projection year, updated age and demographic indicators were combined with the fixed structural and accessibility indicators to recalculate building-level CPI values. Buildings crossing the fixed threshold

of 0.42 were recorded as new entrants to the renewal-pressure range. Holding the threshold constant ensures that temporal change reflects the modelled attributes rather than annual redefinition of the classification rule.

Measures of renewal exposure

For buildings above the threshold, we calculated four complementary measures: building count, dwelling units, floor area and residential land area. Building count represents the number of separate structures requiring assessment or coordination. Dwelling units approximate the number of affected households and potential relocation cases under demolition. Floor area represents the quantity of built space subject to removal or retrofit. Land area captures the territorial footprint of possible intervention and land reorganization (Supplementary Tables 6–10).

Measures were computed annually for the full stock and separately for urban and rural buildings. This separation is necessary because a rural low-rise building and an urban apartment block have different household, area, tenure and implementation implications. Reporting several exposure measures prevents the numerical dominance of rural building counts from obscuring the concentrated household and floor-area burden of urban buildings⁴².

Fiscal exposure under demolition and in situ renewal

We applied two stylized pathways to buildings above the threshold⁴³. All monetary values are expressed in constant 2020 prices^{44–46}. The demolition pathway estimates compensation exposure only; it is not a total redevelopment budget and excludes replacement construction, administrative expenditure, financing, disruption and possible land-value recovery. The in-situ pathway estimates direct engineering investment for renovation and excludes financing, maintenance and household disruption. The two fiscal accounts are therefore compared as orders of magnitude, not as equivalent welfare costs.

Demolition compensation was estimated separately for urban and rural buildings to reflect different tenure and valuation institutions. Rural compensation combines homestead compensation, structural replacement cost, a depreciation or newness factor and indoor-decoration allowances. Urban compensation equals floor area multiplied by observed housing prices; the lower bound uses the direct product and the upper bound applies a factor of 1.1. This design avoids applying an urban commodity-housing price system to rural homestead-related compensation (Supplementary Tables 11 and 12).

Unit costs for in situ renewal were calibrated from government-approved old residential community renovation projects in Quanzhou. Approved investment was divided by renovated building area. The benchmark uses the 2020–2024 Licheng District programme, which has the widest coverage in the observed

local project set; the low and high values use the minimum and maximum among comparable projects. The resulting scenarios are 47,103 and 117-yuan m⁻². Project names, approval records, investment amounts and renovated areas are documented in the accompanying source-data workbook. The same engineering-cost schedule is applied to urban and rural floor area, while differences in total investment arise from the amount and location of priority stock. This assumption provides a standardized exposure scenario and does not imply identical project content or implementation difficulty (Supplementary Tables 13 and 15).

Carbon accounting and scenario uncertainty

Demolition-stage emissions were estimated using a provincial building-carbon accounting method because project-specific records on machinery, work shifts, waste transport and disposal were unavailable. Building morphology and floor area were combined with reported coefficients; all inputs and equations are provided in the Supplementary Information. For retained buildings, we estimated a baseline annual operational emissions exposure from Fujian residential energy consumption and the national standard-coal CO₂ emission factor⁴⁷. The per-capita baseline was applied to the demographic scenarios. These are deliberately different accounts: demolition emissions are a one-off stage estimate, whereas operational emissions are annual baseline exposure before any realized retrofit saving. The analysis is not a full comparative life-cycle assessment and excludes replacement construction, material recovery and future grid decarbonization (Supplementary Tables 14 and 15).

Uncertainty is represented through structured scenarios. Population uncertainty is captured by the low-, medium- and high-growth projections. Fiscal uncertainty is represented by lower- and upper-bound demolition compensation and three locally calibrated renovation-cost settings. The main results are reported as ranges across these assumptions. Supplementary analyses also document the parameters used for spatial density mapping and carbon and cost accounting (Supplementary Tables 3 and 13–15).

The scenario design tests whether the central findings—the inherited dominance of the 2020 stock, spatial clustering and the separation of pathway accounts—persist under plausible demographic and cost assumptions. It does not constitute an exhaustive global sensitivity analysis. Alternative CPI weights, policy anchors, population-allocation rules and spatial bandwidths remain important targets for robustness analysis in future applications.

Interpretation of projections

The outputs are relative priority, conditional stock-ageing projections and pathway-specific exposure. They do not model resident decisions, developer participation, project sequencing, adaptive reuse, future construction, realized retrofit depth or market response. Results should therefore be interpreted as planning

diagnostics for long-term fiscal and carbon governance, not as exact forecasts of public expenditure, emissions or the number of projects that will be implemented.

Limitations

First, the analysis relies on administrative building records. Their coverage of construction year, structure, height, dwelling units, floor area and land occupation is unusually detailed, but reporting and classification error remain possible. Topology correction, attribute cleaning and consistency checks reduce these problems but cannot remove uncertainty in construction year, structural type or storey count.

Second, demographic data are observed at village level and allocated to buildings by floor area. This procedure preserves village totals and allows demographic conditions to enter a building-level analysis, but it does not observe within-village variation in occupancy, household composition or vacancy. It also produces a simplified distribution of per-capita floor area within each village. Address-level population or occupancy data would improve the social-need component.

Third, the projection intentionally holds the number of buildings, structural type, storeys and accessibility constant. This isolates ageing of the 2020 stock but omits future construction, demolition, infrastructure investment, land-use change and endogenous redevelopment. The results are therefore conditional on a static physical stock and should not be read as a complete forecast of Quanzhou in 2050.

Fourth, the CPI simplifies a decision process that also depends on ownership, measured engineering condition, heritage value, resident preferences, displacement risk, developer incentives, environmental performance and political feasibility. Entropy-derived weights within dimensions, equal weights across dimensions and a single policy-calibrated threshold are transparent benchmark choices, not claims that all indicators or dimensions are normatively equivalent. A stronger robustness package would test alternative weighting systems, policy anchors and demographic-allocation procedures.

Fifth, pathway estimates represent exposure rather than realized cost or carbon outcomes. Compensation excludes several social and redevelopment costs, renovation investment excludes maintenance and financing, demolition carbon excludes replacement construction, and operational emissions are a baseline rather than an achieved post-retrofit value. The common rural and urban renovation unit costs further abstract from differences in technical scope and service standards. The results are best read as order-of-magnitude accounts that reveal where additional project-level appraisal is most necessary.

Finally, the empirical estimates come from one Chinese city. Quanzhou is analytically valuable because it combines rapid construction, urban–rural heterogeneity and detailed building records, but its counts, thresholds and valuation parameters are context specific. Land tenure, housing markets, compensation systems, energy supply and local fiscal capacity vary widely. The transferable contribution is the mechanism: concentrated construction cohorts can create synchronized ageing, spatially clustered renewal priority and pathway-dependent exposure. Multi-city and cross-national applications are needed to establish the boundary conditions of that mechanism.

Data availability

The study integrates residential-building records from the First National Survey of Comprehensive Natural Disaster Risk, administrative boundaries, land-use surveys and population statistics from the Seventh National Population Census. These sources were spatially matched to construct the building-level analytical database.

Some source records originate from government statistical systems and are subject to administrative access restrictions. The processed data supporting the analyses, figures and tables are available through the Figshare repository associated with this study⁴⁸, subject to the conditions described there.

Code availability

Data cleaning, spatial matching, indicator construction, threshold calibration, demographic projection, exposure accounting and figure preparation were implemented with ArcGIS and Python. Code and figure-ready data needed to reproduce the principal results are available through the associated Figshare repository⁴⁸.

References

1. Seto, K. C., Sánchez-Rodríguez, R. & Fragkias, M. The new geography of contemporary urbanization and the environment. *Annu. Rev. Environ. Resour.* **35**, 167–194 (2010).
2. Seto, K. C., Güneralp, B. & Hutyra, L. R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl Acad. Sci. USA* **109**, 16083–16088 (2012).
3. Shi, L., Leichtle, T., Huang, X., Wurm, M. & Taubenböck, H. The decreasing housing utilization efficiency in China's cities. *Nat. Cities* **2**, 70–80 (2025).
4. Fishman, T., Schandl, H. & Tanikawa, H. Stochastic analysis and forecasts of the patterns of speed, acceleration, and levels of material stock accumulation in society. *Environ. Sci. Technol.* **50**, 3729–3737 (2016).
5. Creutzig, F. et al. Urban infrastructure choices structure climate solutions. *Nat. Clim. Chang.* **6**, 1054–1056 (2016).
6. Nachmany, H. & Hananel, R. The urban renewal matrix. *Land Use Policy* **131**, 106744 (2023).
7. Couch, C., Sykes, O. & Börstinghaus, W. Thirty years of urban regeneration in Britain, Germany and France: the importance of context and path dependency. *Prog. Plann.* **75**, 1–52 (2011).

8. Weber, R. Extracting value from the city: neoliberalism and urban redevelopment. *Antipode* **34**, 519–540 (2002).
9. Smith, N. New globalism, new urbanism: gentrification as global urban strategy. *Antipode* **34**, 427–450 (2002).
10. Lai, Y., Tang, B., Chen, X. & Zheng, X. Spatial determinants of land redevelopment in the urban renewal processes in Shenzhen, China. *Land Use Policy* **103**, 105330 (2021).
11. Ye, L., Peng, X., Aniche, L. Q., Scholten, P. H. & Ensenedo, E. M. Urban renewal as policy innovation in China: from growth stimulation to sustainable development. *Public Admin. Dev.* **41**, 23–33 (2021).
12. Cao, K., Deng, Y. & Song, C. Exploring the drivers of urban renewal through comparative modeling of multiple types in Shenzhen, China. *Cities* **137**, 104294 (2023).
13. Deng, Y. et al. Regulatory effect of China's city hierarchy on urban redevelopment. *Nat. Cities* **3**, 48–57 (2026).
14. Tanikawa, H. & Hashimoto, S. Urban stock over time: spatial material stock analysis using 4D-GIS. *Build. Res. Inf.* **37**, 483–502 (2009).
15. Krausmann, F. et al. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proc. Natl Acad. Sci. USA* **114**, 1880–1885 (2017).
16. Mehrotra, S. N. & Carter, D. R. Determinants of growth in multiunit housing demand since the Great Recession: an age-period-cohort analysis. *Urban Stud. Res.* 2017, 3073282 (2017).
17. Yung, E. H., Conejos, S. & Chan, E. H. Social needs of the elderly and active aging in public open spaces in urban renewal. *Cities* **52**, 114–122 (2016).
18. Yıldız, S., Kıvrak, S., Gültekin, A. B. & Arslan, G. Built environment design-social sustainability relation in urban renewal. *Sustain. Cities Soc.* **60**, 102173 (2020).
19. Huston, S., Rahimzad, R. & Parsa, A. 'Smart' sustainable urban regeneration: institutions, quality and financial innovation. *Cities* **48**, 66–75 (2015).
20. Lai, Y. & Tang, B. Institutional barriers to redevelopment of urban villages in China: a transaction cost perspective. *Land Use Policy* **58**, 482–490 (2016).
21. State Council of the People's Republic of China. Urban Renewal Plan for the 15th Five-Year Plan Period (State Council Document No. 12, 2026).
22. Quanzhou Municipal People's Government Office. Action Plan for the Renovation of Old Residential Communities and Old Streets (Areas and Communities) in Quanzhou (Quan Zheng Ban [2020] No. 49, 2020).
23. Wang, H. The role of informal ruralization within China's rapid urbanization. *Nat. Cities* **1**, 205–215 (2024).
24. Long, H., Ma, L., Zhang, Y. & Qu, L. Multifunctional rural development in China: pattern, process and mechanism. *Habitat Int.* **121**, 102530 (2022).
25. Zhang, W., Zhang, X. & Wu, G. The network governance of urban renewal: a comparative analysis of two cities in China. *Land Use Policy* **106**, 105448 (2021).
26. Wang, H., Liu, N., Chen, J. & Guo, S. The relationship between urban renewal and the built environment: a systematic review and bibliometric analysis. *J. Plan. Lit.* **37**, 293–308 (2022).
27. Kennedy, C. A. et al. Energy and material flows of megacities. *Proc. Natl Acad. Sci. USA* **112**, 5985–5990 (2015).
28. Zheng, H. W., Shen, G. Q. & Wang, H. A review of recent studies on sustainable urban renewal. *Habitat Int.* **41**, 272–279 (2014).
29. Sun, L., Chen, J., Li, Q. & Huang, D. Dramatic uneven urbanization of large cities throughout the world in recent decades. *Nat. Commun.* **11**, 5366 (2020).
30. Zheng, H. W., Shen, G. Q., Song, Y., Sun, B. & Hong, J. Neighborhood sustainability in urban renewal: an assessment framework. *Environ. Plann. B Urban Anal. City Sci.* **44**, 903–924 (2017).
31. Wang, R., Eisenack, K. & Tan, R. Sustainable rural renewal in China. *Ecol. Soc.* **24**, 32 (2019).

32. Hyra, D. S. Conceptualizing the new urban renewal: comparing the past to the present. *Urban Aff. Rev.* **48**, 498–527 (2012).
33. Kovács, Z., Wiessner, R. & Zischner, R. Urban renewal in the inner city of Budapest: gentrification from a post-socialist perspective. *Urban Stud.* **50**, 22–38 (2013).
34. Zhou, D., Xu, S., Sun, C. & Deng, Y. Dynamic and drivers of spatial change in rapid urban renewal within Beijing inner city. *Habitat Int.* **111**, 102349 (2021).
35. Chen, Z. et al. Public transport accessibility in villages in and around major Chinese cities. *Nat. Cities* **2**, 749–758 (2025).
36. Frantzeskaki, N. & Rok, A. Co-producing urban sustainability transitions knowledge with community, policy and science. *Environ. Innov. Soc. Transit.* **29**, 47–51 (2018).
37. Bai, X. et al. Six research priorities for cities and climate change. *Nature* **555**, 23–25 (2018).
38. Adshead, D., Thacker, S., Fuldauer, L. I. & Hall, J. W. Delivering on the Sustainable Development Goals through long-term infrastructure planning. *Glob. Environ. Change* **59**, 101975 (2019).
39. Zhuang, T., Qian, Q. K., Visscher, H. J., Elsinga, M. G. & Wu, W. The role of stakeholders and their participation network in decision-making of urban renewal in China: the case of Chongqing. *Cities* **92**, 47–58 (2019).
40. Zhang, H., Cong, C. & Chakraborty, A. Exploring the institutional dilemma and governance transformation in China’s urban regeneration: based on the case of Shanghai Old Town. *Cities* **131**, 103915 (2022).
41. Cao, N., Sing, M. C. P. & Hou, C. H. Mapping urban renewal priorities for aging residential districts: a spatial evaluation framework based on EWM–TOPSIS. *J. Urban Manag.* **15**, 657–671 (2026).
42. Schorcht, M., Jehling, M. & Krueger, T. Where are cities under pressure?—An indicator for measuring the impact of building changes on urban density. *Ecol. Indic.* **149**, 110142 (2023).
43. Chen, Y., Feng, S. & Li, M. Impact of housing conditions on resident willingness to withdraw from rural homesteads and preferences regarding compensation and resettlement mode: a dual-sample selection model. *Habitat Int.* **166**, 103577 (2025).
44. Royal Institution of Chartered Surveyors. *Life Cycle Costing 1st edn* (RICS, 2016).
45. International Organization for Standardization. *ISO 15686-5:2017 Buildings and constructed assets—Service life planning—Part 5: Life-cycle costing* (ISO, 2017).
46. National Institute of Standards and Technology. *Life Cycle Cost Manual for the Federal Energy Management Program* (NIST Handbook 135-2020, NIST, 2020).
47. National Development and Reform Commission of the People’s Republic of China. Carbon dioxide emissions accounting method and data verification table (in Chinese). ndrc.gov.cn
<https://www.ndrc.gov.cn/xxgk/zcfb/tz/201605/W020190905516997176703.pdf> (2016; accessed 6 July 2026).
48. Chen, Y., Yan, J. & Zhou, Y. Urban renewal liabilities from ageing housing cohorts. [figshare](https://doi.org/10.6084/m9.figshare.33101048)
<https://doi.org/10.6084/m9.figshare.33101048> (2026).

Acknowledgements

We acknowledge support from the Major Project of the National Social Science Fund of China (grant 21&ZD121) and the National Natural Science Foundation of China (grants 72134008, 72442022 and 72373153).

Author contributions

Y.C., J.Y., Y.L., Q.Z and Y.Z. conceived the study. Y.C. and Y.L. curated the data. Y.C., Y.L. and Y.Z. conducted the analysis and prepared the figures. Y.C. and Y.Z. drafted the manuscript. Y.C., J.Y., Q.Z and Y.Z. revised the manuscript. All authors interpreted the results and approved the final manuscript.

Competing interests

The authors declare no competing interests.

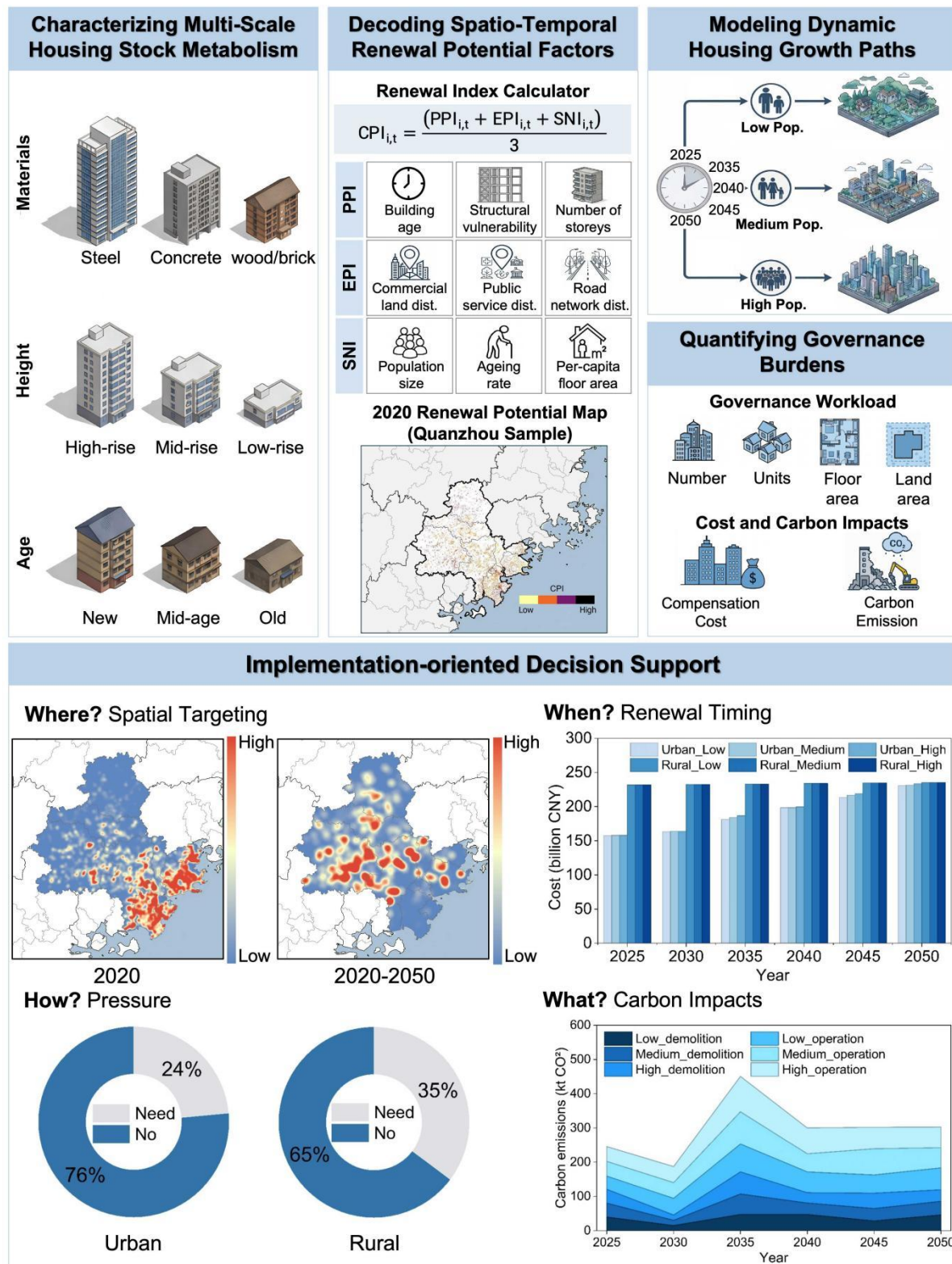


Fig. 1 | Building-level framework for cohort-driven residential renewal.

The P4 framework links Priority, Projection, Pressure and Pathways. Priority combines building age, structural characteristics, locational accessibility and social need. Projection updates the existing stock under demographic and cohort-ageing scenarios while retaining a policy-calibrated threshold. Pressure measures affected buildings, dwelling units, floor area and residential land. Pathways separates demolition compensation, direct renovation investment, demolition-stage emissions and annual operational emissions exposure. The framework identifies where renewal priority concentrates, how it changes and which fiscal and carbon accounts are activated by alternative interventions.

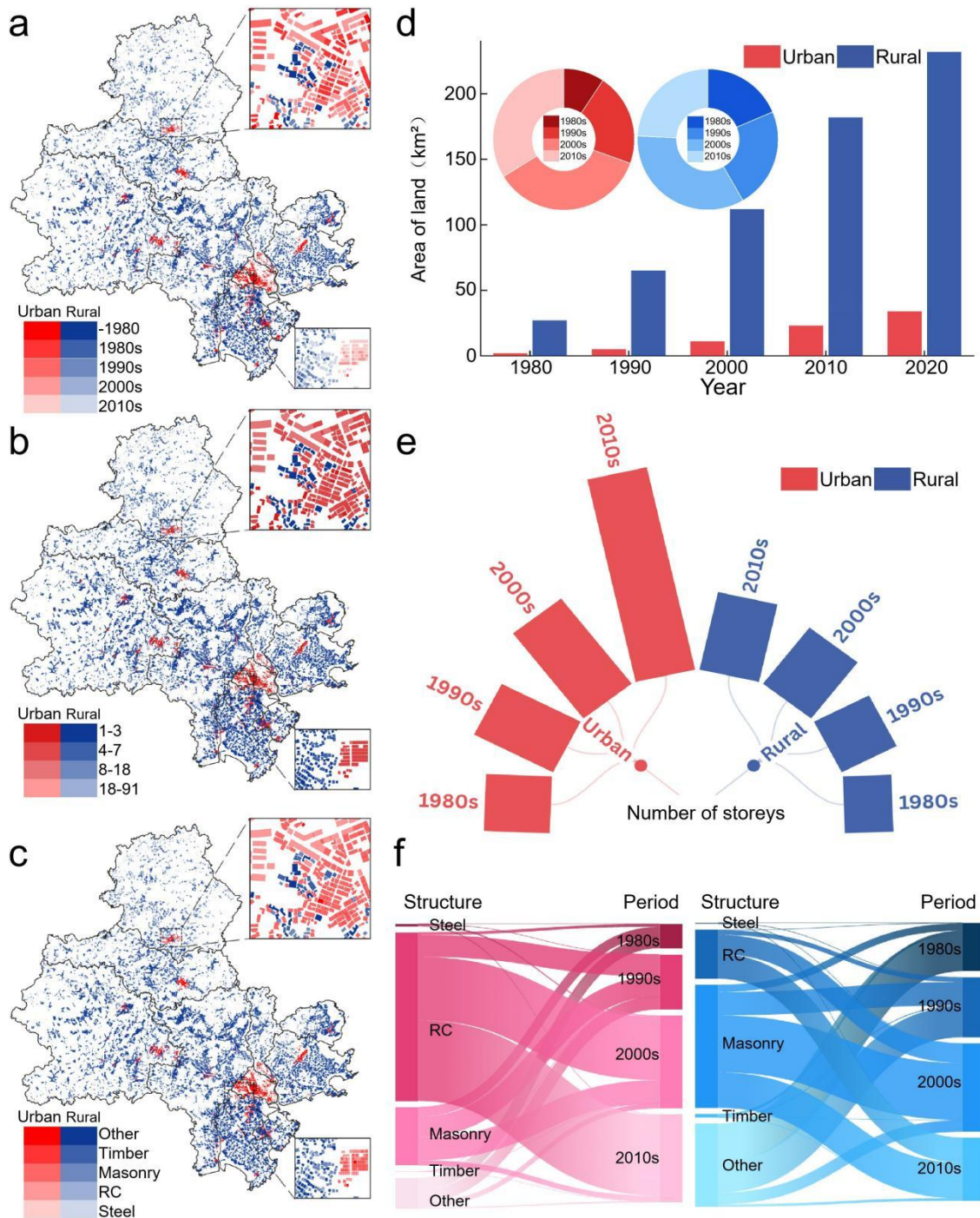


Fig. 2 | Formation of residential building cohorts in Quanzhou from 1980 to 2020.

a–c, Spatial distributions of buildings by construction period (a), number of storeys (b) and structural type (c). d, Accumulation of residential built-up area across successive construction waves. e, Mean number of storeys in newly constructed housing by decade, showing increasing verticality in urban areas. f, Changes in structural materials, including the rise of reinforced concrete and the decline of timber construction.

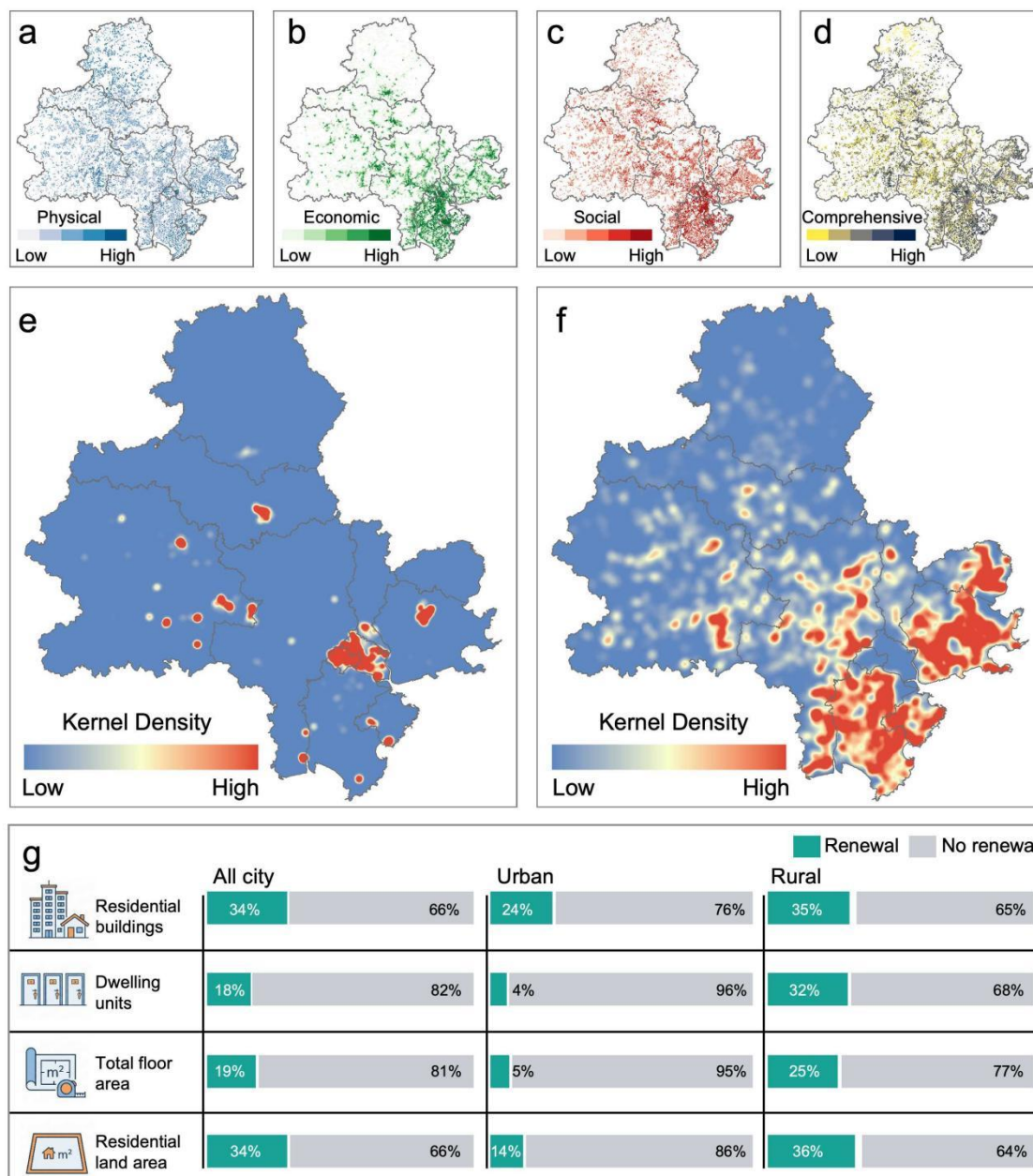


Fig. 3 | Building-level geography of residential renewal priority.

a, Physical Potential Index, combining building age and structural characteristics. b, Economic Potential Index, measuring accessibility to commercial land, public facilities and roads. c, Social Need Index, combining allocated population, older population and residential-space pressure. d, Comprehensive Urban Renewal Priority Index (CPI). e,f, Kernel density of urban (e) and rural (f) buildings above the policy-calibrated CPI threshold. g, Composition of the above-threshold stock. Rural results are a diagnostic under the common threshold and do not indicate formal inclusion in the urban renovation programme.

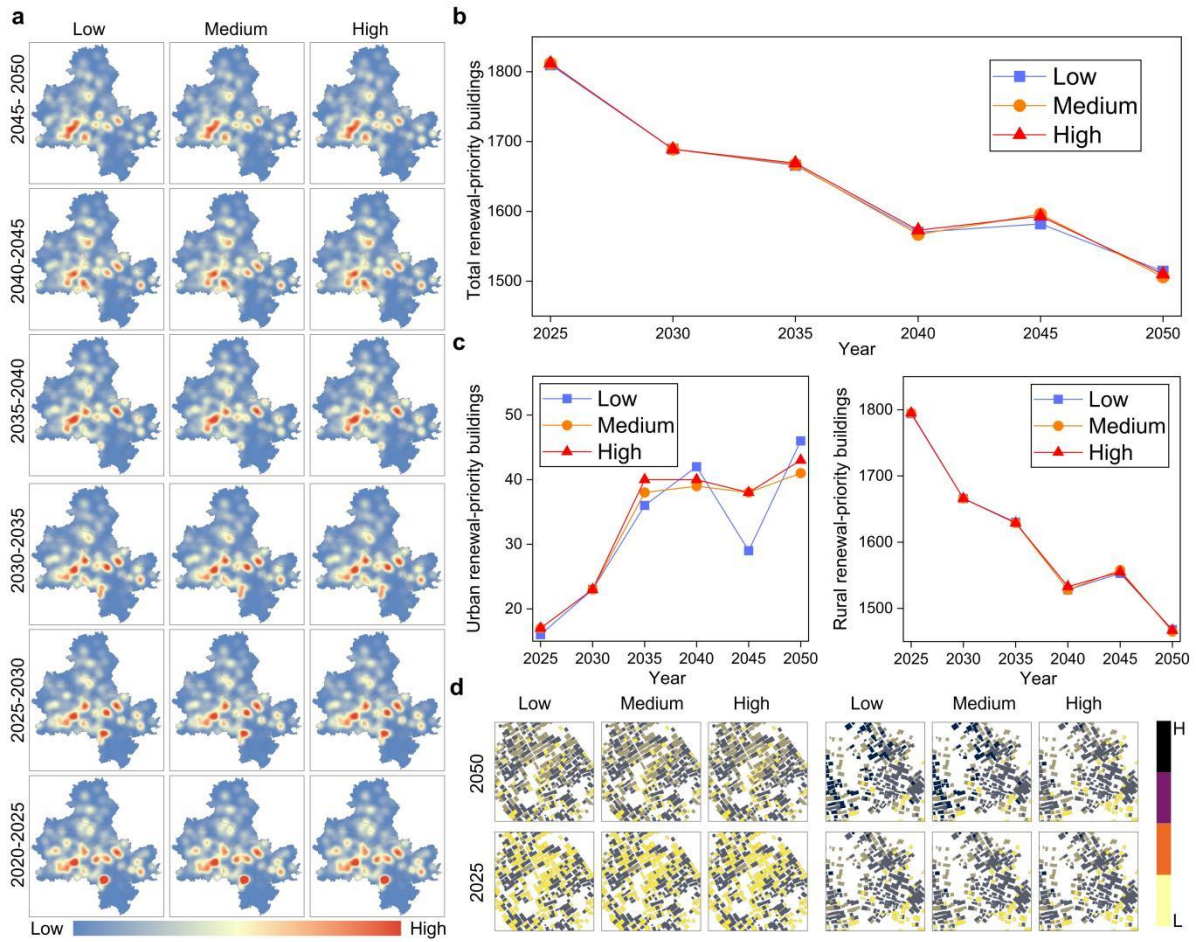


Fig. 4 | Cohort-driven change in residential renewal pressure from 2025 to 2050.

a, Spatial distribution of buildings newly crossing the fixed CPI threshold in each five-year period under low-, medium- and high-population scenarios. b, Number of new entrants by period and scenario. c, Urban and rural entrants by period. d, Building-level examples of threshold status in selected urban and rural areas in 2025 and 2050. Projections hold the observed building stock constant and update age and demographic attributes.

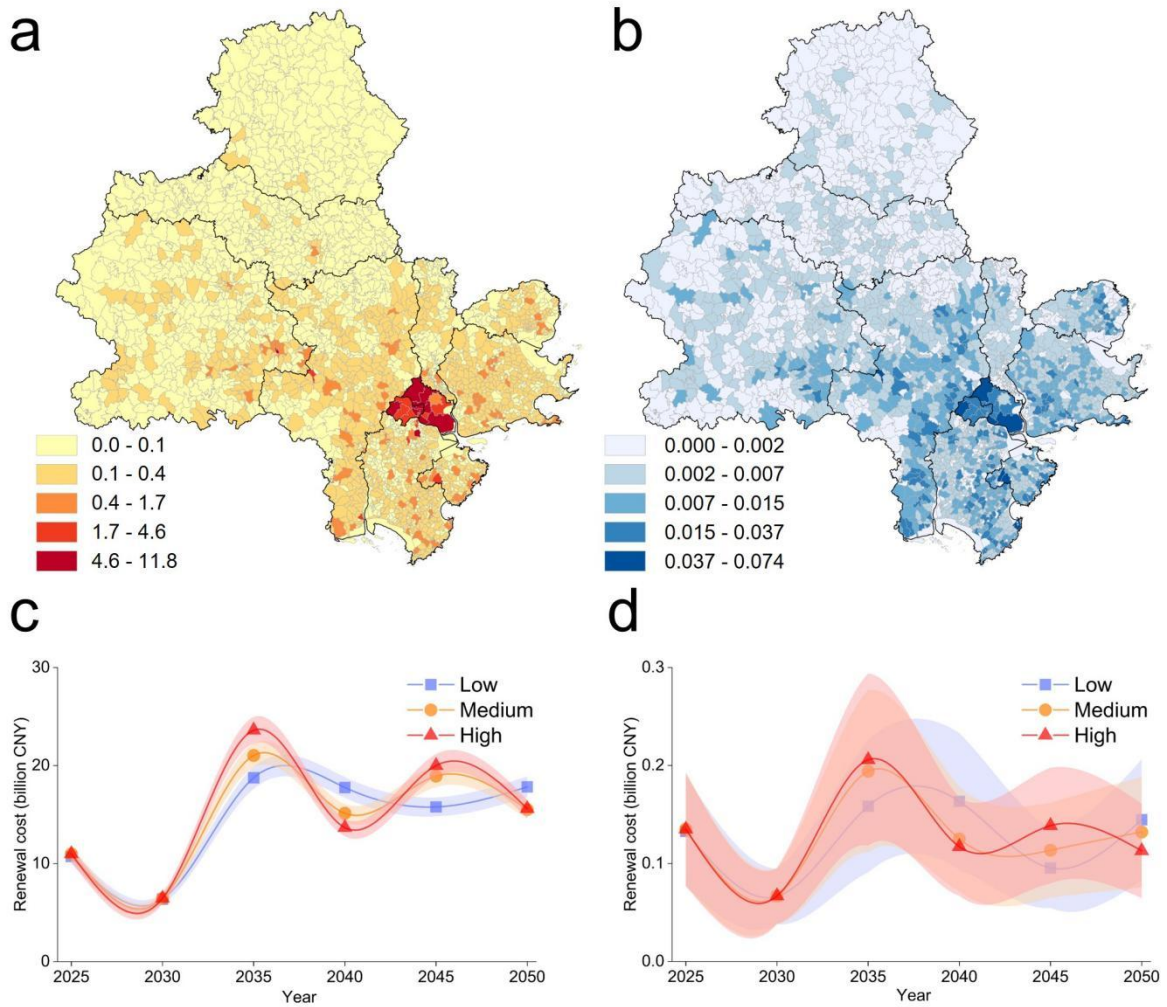


Fig. 5 | Fiscal exposure under demolition and in situ renewal.

a,b, Village-level demolition-compensation exposure (a) and direct in situ renovation investment (b) for the 2020 priority stock. c,d, Five-year exposure associated with buildings newly crossing the threshold under three demographic scenarios for demolition compensation (c) and in situ renovation (d). Compensation and renovation investment are different accounting concepts and do not constitute a complete life-cycle cost comparison.

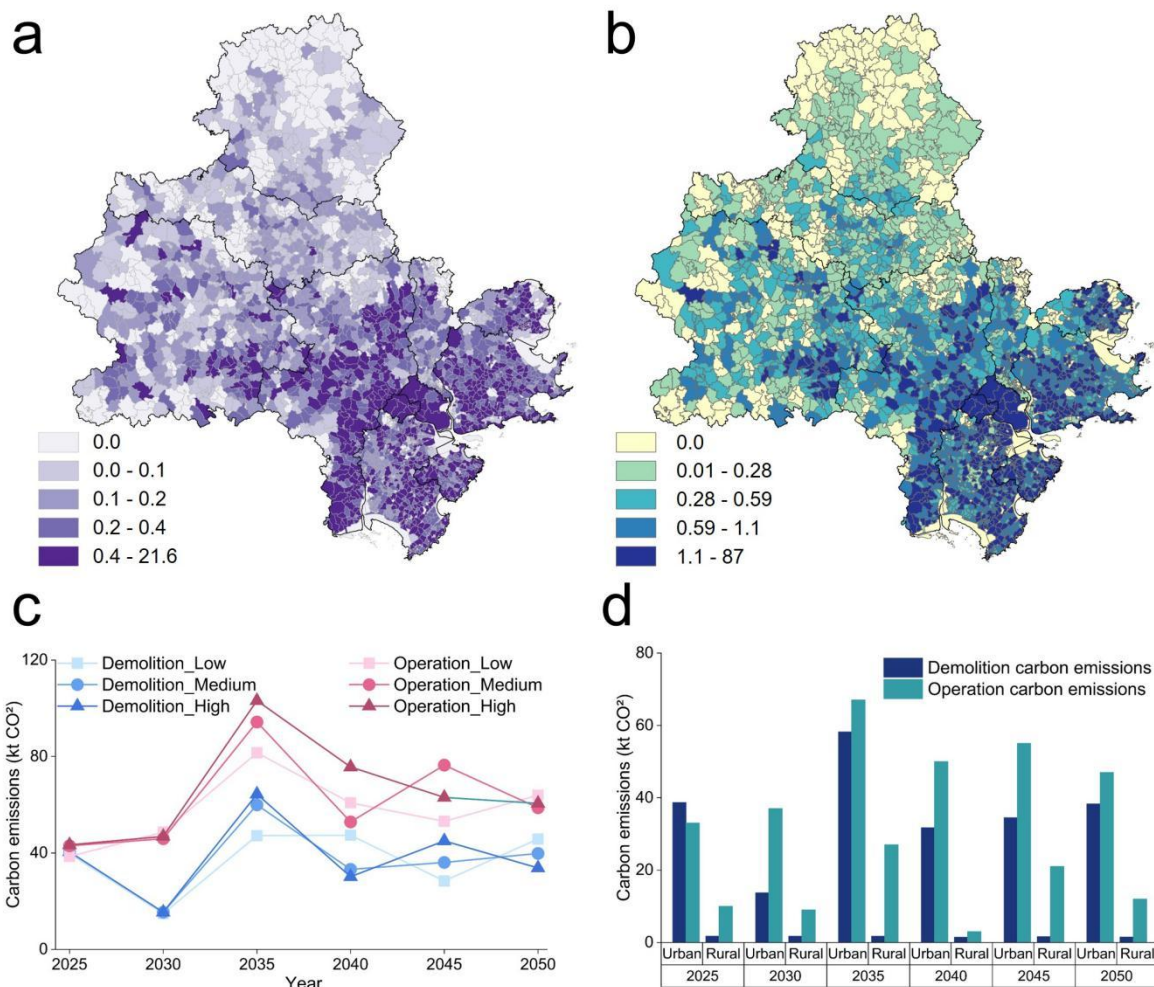


Fig. 6 | Carbon accounts under demolition and retention pathways.

a, Village-level demolition-stage emissions for the 2020 priority stock. b, Annual baseline operational emissions of the same stock if retained. c, Demolition-stage emissions and annual operational exposure for buildings newly crossing the threshold under three demographic scenarios. d, Urban–rural differences in the two accounts. Demolition emissions are one-off stage estimates, whereas operational emissions are annual baselines before realized retrofit savings; they are not directly comparable life-cycle totals.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryinformationSI.docx](#)