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Scenario modelling shows urban planning can reduce city-scale GHG emissions in transport and buildings by 14% in 2050

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Abstract

Urban planning (UP) is a key lever for municipal climate mitigation, relevant for both reducing greenhouse gas (GHG) emissions in urban transport and within the building sector. However, it is unclear how large the municipal mitigation potential of UP is. Here, we develop scenarios that explicitly consider the contribution of new settlements between 2025 and 2050 for both transport—by reducing the distance travelled by cars and by modal shift-, and buildings—by supporting more compact building forms that reduce energy use and construction demand. We find that UP—a focus on compact design, mixed use, and low-carbon transport infrastructure—can reduce future GHG emissions by 14% compared to business as usual, with about equal contributions from transport and building sectors, notably including construction. Compact UP benefits the public purse, but requires land markets that internalize social costs. Our analysis highlights the importance of developing and rapidly growing cities in Asia and Africa in supporting UP-related mitigation efforts.

1. Introduction

Urban areas are central to climate action because they concentrate both greenhouse gas (GHG) emission sources and mitigation opportunities. Urban planning (UP), as a core municipal lever, shapes long-lived infrastructures that determine patterns of energy use, mobility, and exposure to climate risks. Decisions on density, land-use mix, and spatial configuration directly influence transport demand, building energy consumption, and infrastructure requirements over decades. At the same time, UP is not only a mitigation instrument but also a critical mechanism for adaptation, affecting heat exposure, flood risk, and resilience to climate extremes. Compact, well-designed urban form can reduce energy demand while enhancing adaptive capacity through reduced land consumption, improved accessibility, and more efficient service provision. Given the rapid pace of urbanization—particularly in Asia and Africa—the design of new settlements over the coming decades represents a decisive window for shaping long-term emissions trajectories and climate resilience (Seto *et al* 2014, Creutzig *et al* 2015a, Pathak *et al*. 2015, Ürge-Vorsatz *et al* 2020).

A substantial body of literature has established UP as a key 'avoid' strategy in climate mitigation. The IPCC Sixth Assessment Report (AR6) highlights that urban form and infrastructure can reduce emissions by avoiding unnecessary energy service demand, particularly in transport and buildings (IPCC 2022). Empirical and modelling studies show that compact, transit-oriented development (ToD) reduces travel distances, enables modal shift, and lowers per-capita transport emissions (Newman and Kenworthy 1999, Ewing and Cervero 2010, Creutzig et al 2015b, Wagner et al 2026). Similarly, UP influences building-related emissions by shaping floor space demand, construction intensity, and operational energy use (Ürge-Vorsatz et al 2015, Grubler et al 2018, Creutzig et al 2022). However, despite this well-established importance, large-scale integrated assessment models (IAMs), which underpin much of global climate policy analysis, typically lack explicit spatial representation of urban form and planning decisions. When urban-related interventions are considered, they often overlook consistency between the transport and building sectors, which are commonly modelled as separate and not interlinked (Mastrucci et al 2023). As a result, the mitigation potential of UP is only partially captured in IAM-based scenarios, leading to systematic underrepresentation of 'avoid' strategies relative to negative emissions, technological substitution and efficiency improvements (van Vuuren et al 2017, Creutzig et al 2018, Wilson et al 2020).

The lack of explicit spatial representation of urban form and planning decisions has been recognized as a persistent concern yet to be addressed in the literature, with or without efforts to provide potential improvements. A comparison of scenarios and modelling methods indicated that urban form is not represented across an overwhelming majority of both global integrated and energy models (Guivarch et al 2022). Newer versions of sustainable development pathways based on multi-model analysis included a thematic focus on resilient communities as one of the three narratives, while the main emphasis remained to be community development and resource sharing (Soergel et al 2024). Endogenous or exogenous representation of UP indicators explicitly or implicitly in these sustainable development pathways continued to be underrepresented, although with some efforts to consistently include floor space per capita as an energy service indicator.

Other studies aimed to provide mitigation pathways for a group of urban areas with the largest emissions footprint across regions, also integrating aspects of land use efficiency in preserving surrounding carbon sinks and enabling decarbonization efforts (Kılkış 2022). Another recent study considered pathways to decarbonize urban passenger transport in the major megacity of Tokyo with improved representation of travel behaviours and choices related to energy technology and location (Zhang et al 2025). Strategies to avoid emissions were considered in the context of the Asia-Pacific Integrated Model. However, the necessity of resolving the representation of urban form and planning decisions for all urban areas of the world remain unanswered in ways that can be commensurate with the existing possibilities and its enabling role for emissions reductions at the urban scale on a comprehensive basis.

A recent summary of mitigation options (modernized stabilization wedges, Johnson and Staffell 2026) offers a useful lens through which to clarify how urban options are considered, or not, in the mainstream literature. In their updated framework, a wedge represents any strategy that can scale linearly over 30 years to avoid 2 $GtCO_2e$ per year by 2050—roughly 4% of global GHG emissions. Within the transport sector, they identify shifting passenger travel to public transport (PT) (∼19% of global passenger travel) and avoiding car trips through active travel (∼17% of global passenger travel) as distinct wedge-scale strategies, with the transport sector collectively capable of delivering up to 6–10 wedges. These strategies are, however, treated as isolated behavioural interventions rather than as outcomes of urban structure. The role of compact, mixed-use urban development in generating precisely these modal shifts—by shortening trip distances, increasing transit viability, and reducing car dependence—is not captured as a dedicated strategy. Furthermore, while the framework identifies buildings as a separate sector with 1–3 wedges of potential, largely through heat pumps and improved insulation, it does not account for the energy savings that higher-density urban form itself delivers through smaller dwelling sizes, shared building envelopes, and reduced heating and cooling loads. In short, UP as a strategy to reduce GHG emissions remains ignored, leaving Creutzig et al (2015a) as the main but insufficient contribution considering GHG emission savings via UP.

Here, we aim to close this gap by explicitly integrating UP dimensions into IAM-based scenario analysis. We employ the MESSAGEix framework (Huppmann et al 2019), including its building and transport modules, and calibrate it using a novel dataset covering more than 10 000 cities across different world regions and four different urban types. We thus explore variation in urban form, density, and infrastructure, and simulate how alternative planning pathways influence emissions trajectories consistently across transport and building sectors. By mapping the role of urban spatial structure into IAM modelling, we quantify the mitigation potential of planning decisions associated with new settlements between 2025 and 2050. Overall, we provide a systematic assessment of how UP can contribute to global climate targets.

2. Methods

Scenario design and modelling framework. We quantify the GHG mitigation potential of urban densification across 11 422 cities from 2025 to 2050 using two contrasting scenarios: a business-as-usual (BAU) trajectory, in which built-up area expands with population according to historically observed density elasticities, and an UP scenario,

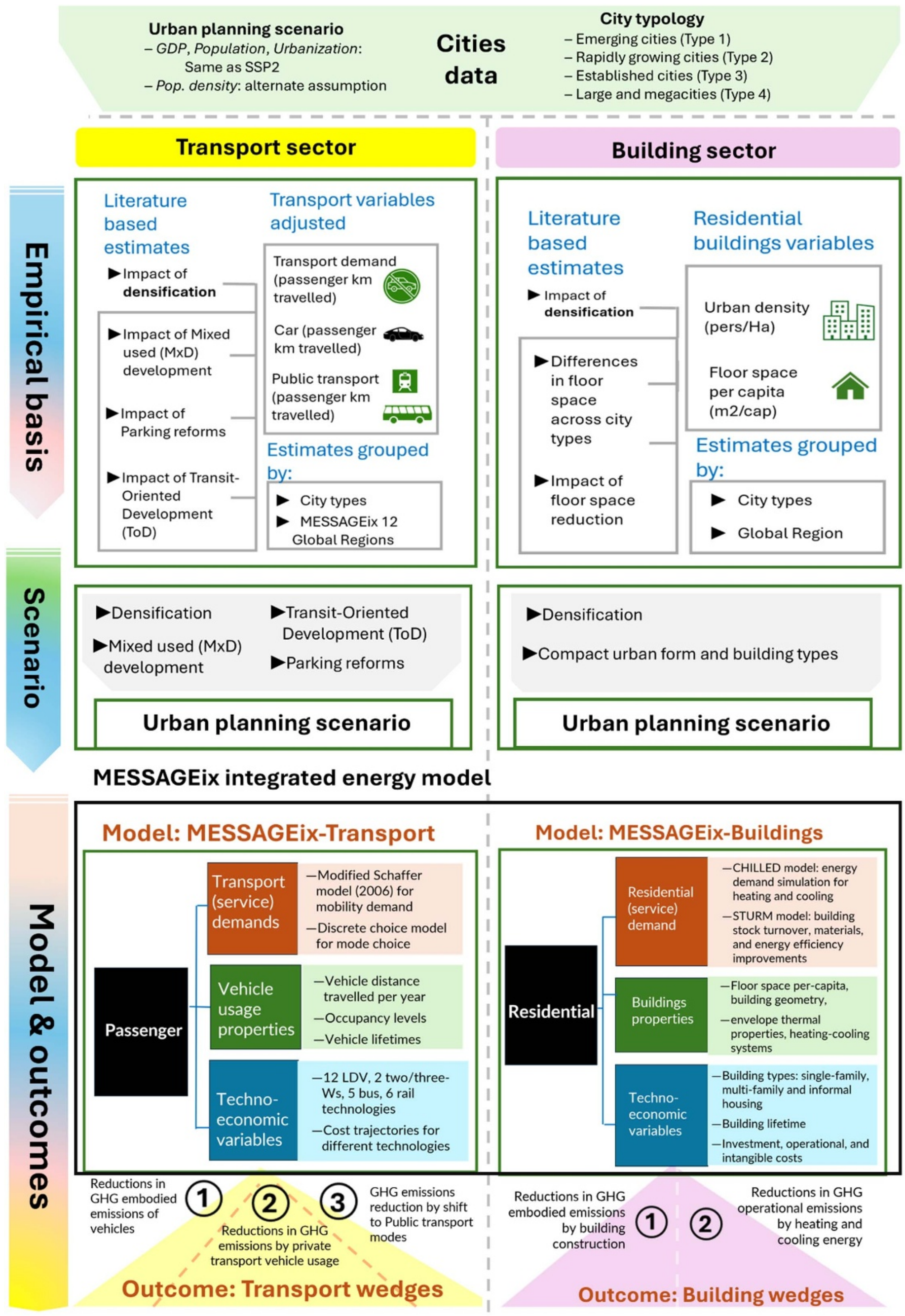

Figure 1. Scenario design, empirical basis, model used and outcomes.

in which urban growth occurs exclusively through densification and limited increase in spatial footprint. City-level population projections follow Kii (2021), matched by name, region, and population size; unmatched cities are assigned average growth rates by city type and region. Scenario impacts are assessed across the building and transport sectors using MESSAGEix-Buildings (Mastrucci *et al* 2021, 2024) and MESSAGEix-Transport, two bottom-up demand-side extensions of the MESSAGEix-GLOBIOM IAM (Huppmann *et al* 2019). MESSAGEix-Transport projects passenger kilometres travelled as a function of GDP and population elasticities, disaggregated across five modes and multiple powertrain technologies, with consumer adoption barriers captured via discrete-choice disutility costs (Kishimoto *et al* 2026). MESSAGEix-Buildings combines the CHILLED model for spatially resolved heating and cooling demand and the STURM stock turnover model tracking construction and renovation dynamics and energy efficiency-related investment (Mastrucci *et al* 2021). Both models are (soft)-linked to MESSAGEix-GLOBIOM, exchanging energy price signals and sectoral demand projections to ensure supply-demand consistency. Figure 1 summarizes the model design.

For orientation: in the result section in figures 2 and 4, we will focus on the outcome metrics (wedges). In contrast, in table 2, we will focus on the contribution of the four different transport scenarios.

City typology and sector-specific density linkages. We characterize urban spatial structure relying on a global typology of 11 422 cities (⩾50 000 inhabitants) derived from the GHSL-UCDB R2024A database (Montfort *et al* 2026; see figure 1 therein for a map of all cities according to type), classifying cities into four types via Deep Embedded Clustering across demographic, socioeconomic, and biophysical dimensions: Emerging cities (Type 1), Rapidly growing cities (Type 2), Established cities (Type 3), and Large and megacities (Type 4). These city types are incorporated into MESSAGEix-Buildings by disaggregating urban population shares at the national and regional level. The density–floor space relationship is estimated via log–log ordinary least square regression across 40 cities across different world regions ($R^2 = 0.68$; elasticity $= -0.86$), linking urban density to floor space per capita. Predicted values are differentiated by city type and scaled to preserve consistency with existing MESSAGEix-Buildings regional projections. Future floor space trajectories under BAU and UP are derived by applying the estimated elasticity to scenario-specific density pathways, treating density-driven changes as independent of affluence-driven floor space growth already embedded in the baseline projections. In the transport sector, higher densities, mixed development and parking management under the UP scenario reduce vehicle-kilometres travelled and shift mobility toward PT, and indirectly reduce the footprint from car manufacturing. In the building sector, compact cities lower floor space per capita and, consequently, material demand for new construction and space heating and cooling demand (additionally modulated by housing type composition).

For the transport sector, increases in density are associated with reduced demand for car travel (including shift to non-motorized transport) and modal shift to PT. The respective values for these impacts are calculated based on a meta-analysis of earlier studies reported in Ahlfeldt and Pietrostefani (2019), Tuffour *et al* (2025) & Aston *et al* (2021). The elasticity values for reduction in car use are scaled to population growth across cities, whereas the elasticity values for modal shift to PT are scaled to existing infrastructure. In addition to the impact of density, we consider three additional aspects of UP, namely ToD, parking reforms, and mixed-use development on both car use reduction and modal shift to PT, with each scenario element scaled to city type and region. The details for these scenario elements, their implementation in the model and supporting evidence base is given in the methods section below. In the headline **Urban planning (UP) scenario**, we consider the cumulative impact of these four elements combined. In terms of outcomes, we report the impact of UP on urban passenger transport-related CO_2 emissions, both from operating the vehicles as well as emissions avoided due to lower demand for manufacturing new cars.

For detailed information see the supplementary material and figures S1–S16.

3. Results

3.1. Global UP wedge

The global potential of UP between 2025 and 2050 is cumulatively 7 Gt CO_2 by 2050, or 14% compared to baseline in 2050, dominated by savings in building construction (figure 2). Marginally, this corresponds to about 0.5 Gt CO_2 by year in 2050, in the order of 1% of global GHG emissions in 2025 (including non-CO_2 emissions).

As background and for contextualization, global GHG emissions, including land use, land use change, and forestry, reached approximately 60.6 Gt CO_2e in 2025 (Climate TRACE 2026) (table 1). Fossil fuel and cement CO_2 emissions alone are projected at 38.1 Gt CO_2 for 2025 (Friedlingstein *et al* 2025). Road transport emitted just over 6.0 Gt CO_2 in 2024, 8% above 2015 levels (IEA 2025a). Passenger cars and vans account for over 60% of road emissions (about 3.6 Gt CO_2) (IEA 2025a). The buildings and construction sector is the largest emitting sector when embodied carbon is included. In 2023, operational building emissions reached a record 9.8 Gt CO_2, and embodied carbon from materials such as steel and cement used in construction contributed a further 2.9 Gt CO_2, bringing the building sector total to approximately 12.7 Gt CO_2, which is equivalent to 34% of global energy- and process-related CO_2 emissions (UNEP & GlobalABC 2025). Operational emissions can be disaggregated into direct combustion (approximately 3.0 Gt CO_2) and indirect emissions from electricity and heat supply (approximately 6.8 Gt CO_2) (IEA 2023).

While urban passenger transport and building emissions together amount to close to 16 Gt CO_2 per year, our UP component considers 30% of these emissions. The reason is that our UP scenario only investigates specific activities and related GHG emissions. Specifically, in transport, we (i) only consider urban travel, and exclude long-distance travel ($\sim$10%–50% depending on the region); (ii) consider only the share of population covered by our cities dataset which is between 40% and 80% of urban populations for different regions; (iii) exclude emissions from two-wheelers. Within the building sector, we (i) only include residential, but not commercial buildings, or industry; (ii) consider only for space heating and cooling in operational energy use, while all other, notably household electricity use is excluded; (iii)

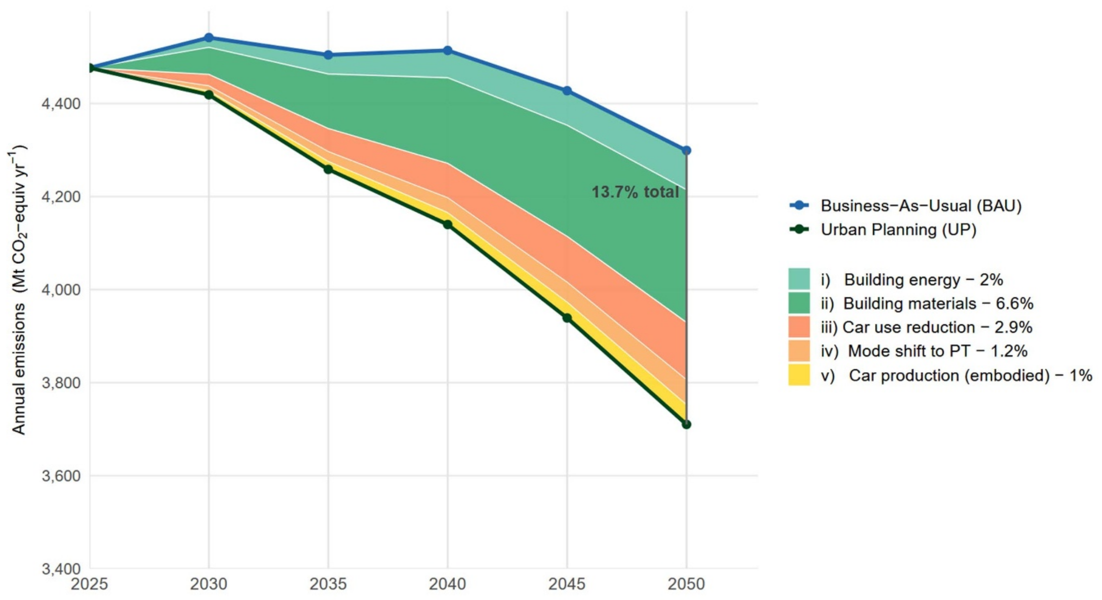

Figure 2. Global urban planning wedge as realized by compact urban development in emission reductions via building energy use, building materials and construction needs, car use, mode shift to public transport and car production (embodied emissions). The five different outcome wedges are defined in figure 1.

Table 1. Global GHG emissions by sector and aggregate, most recent available year.

Sector/aggregate	Emissions	Share	Source
Global GHGs incl. LULUCF (2025)	∼60.6 Gt CO_2e	100%	Climate TRACE (2026)
Fossil fuel & cement CO_2 only (2025)	∼38.1 Gt CO_2	∼63%	Friedlingstein *et al* (2025)
Road transport (2024)	∼6.0 Gt CO_2	∼10%–11%	IEA (2025a)
Of which: passenger cars & vans	∼3.6 Gt CO_2	∼6%	IEA (2025a)
Buildings—operations only (2023)	∼9.8 Gt CO_2	∼16%–18%	UNEP & GlobalABC (2025)
Direct combustion	∼3.0 Gt CO_2	∼5%	IEA (2023)
Indirect (electricity & heat)	∼6.8 Gt CO_2	∼11%	IEA (2023)
Buildings + construction incl. embodied carbon (2023)	∼12.7 Gt CO_2	∼21%	UNEP & GlobalABC (2025)
Of which: embodied carbon (materials)	∼2.9 Gt CO_2	∼5%	UNEP & GlobalABC (2025)
Urban planning component considered	∼4.5 Gt CO_2	∼7%–8%	This paper

account in material demand only for six materials—aluminium, concrete, copper, glass, steel, and wood.

If our results scale to commercial buildings, smaller settlements (not in our dataset), and motorcycles, the potential of UP for climate change mitigation may hence double.

3.2. UP potential across types and regions

UP's mitigation potential differs across geographies (figure 3). Reductions range from 5% to over 20% relative to BAU trajectories depending on city location and associated population and economic growth rates. Across all regions, no single intervention dominates universally: Asia's mitigation portfolio is led by the construction sector and associated building materials (∼50% of regional savings), mirroring urbanization dynamics and need for additional housing. In contrast, African cities derive the largest share of savings from transit-oriented development (ToD, ∼35%) (partially reflecting a counterfactual assumption of comparatively low per capita growth in carbon intensive housing). Europe's savings are most strongly associated with parking reduction strategies (∼22%). A key reason is that most European cities are stagnant, providing relatively more opportunity space for demand-side transport policy in already-dense, transit-served urban environments. North America's portfolio is comparatively balanced. Here, mixed-use development (∼18%) emerges as the leading contributor.

In the transport sector, CO_2 reductions of strategies are channelled both through car use reduction and mode shift to PT, and patterns of respective shares vary substantially across city types, and regions. Both effects (car share reduction, modal shift) contribute across all regions. However, car use reduction generally dominates in higher-income, car-dependent contexts, specifically in wealthy North American cities (established cities; type 3) (−19.6 Mt yr^{-1} by 2050) and Asia (−7.0 Mt yr^{-1}). In contrast, mode shift to PT constitutes a dominant share in African and

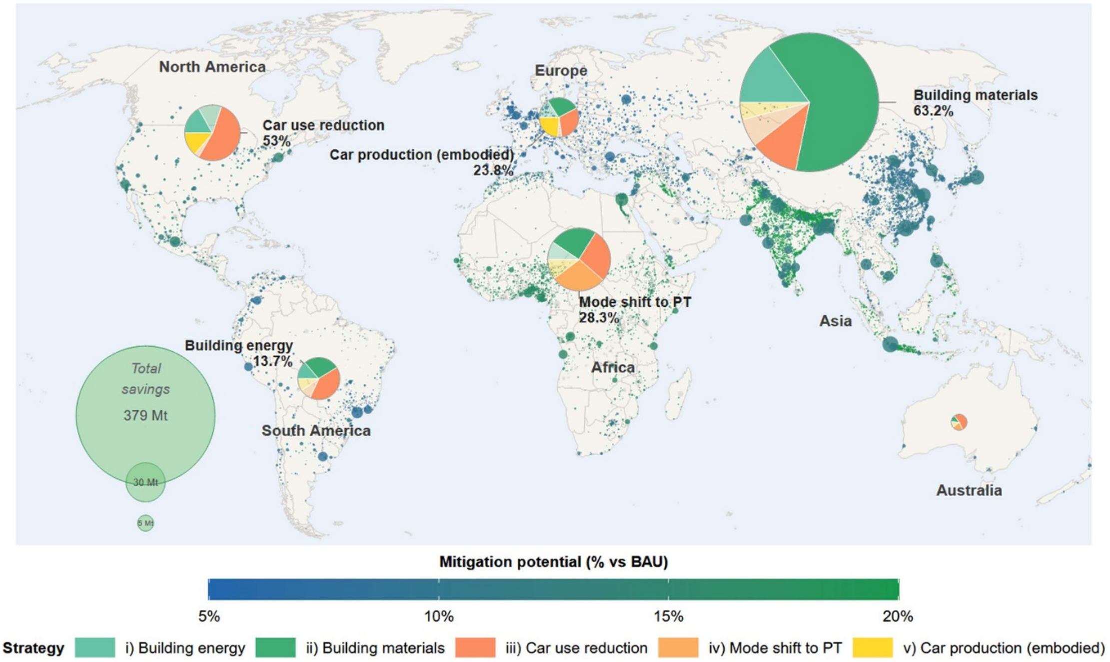

Figure 3. Global urban planning climate change mitigation potential mapping demonstrates highest contributions by South and South East Asian cities, dominated by savings in the construction sector. World map showing the spatially resolved mitigation potential (% reduction vs business-as-usual, BAU) of five urban decarbonization strategies—building energy efficiency (i), building materials (ii), car use reduction (iii), mode shift to public transport (iv), reduction in car production (embodied emissions) (v)—applied to cities worldwide. Dot colour indicates mitigation potential per city (colour scale: 5%–20% vs BAU). Regional pie charts show the dominant strategy by share of total savings in each continent. Concentric circles (bottom left) denote absolute savings at three magnitude levels (5, 30, and 379 Mt CO_2e).

Asian cities, particularly in emerging cities (type 1) and megacities (type 4). Density strategies generate PT mode shift only in selected city types (notably Asian established cities, type 3), with very little contribution in African cities without improvement in PT services. On the other hand, ToD strategies in African and Asian cities reduce emissions by shifting car-users towards PT options.

Car production emissions reductions constitute a relatively small component across all scenarios, typically around 10%–20% of total reductions. In established European cities, production-related reductions (-4.4 Mt yr^{-1} by 2050) approach the magnitude of operational car use reductions (-6.8 Mt yr^{-1}). Overall, the absolutely smallest reductions from UP strategies on transport are observed in Australia, Europe, and South America, highly urbanized regions with little scope for newly planned towns. The largest cumulative mitigation potential is concentrated in Asia and Africa as expected representing rapidly urbanizing regions with large populations.

The spatial distribution of mitigation potential reveals a concentration of high-opportunity cities (>15% vs BAU, green dots) across South and Southeast Asia, sub-Saharan Africa, and coastal East Asia. These regions are characterized by high urban growth rates, where lock-in of carbon-intensive infrastructure has not yet occurred. Conversely, cities in Europe and North America cluster toward lower relative mitigation values (5%–10%), a reflection of low rates of urban development (i.e. less opportunities to change trajectories by UP). Nonetheless, because of the high number of cities, and high urbanization rates, even small changes per city amount to considerable overall GHG emission savings (bubble sizes, figure 4). Overall, prioritizing low-carbon UP in rapidly urbanizing regions, particularly through compact housing (multi-family housing) and transit-oriented planning, provides the greatest leverage for reducing urban GHG emissions.

Analysis of the UP mitigation potential across city types reveals three key insights (figure 4(a)). First, a pronounced typological asymmetry is evident whereby emerging cities (type 1) account for a disproportionately large share of savings potential in Asia (197 Mt CO_2-eq yr^{-1}). Second, established city types (type 3) exhibit a more geographically distributed savings profile: contributions are observed across Europe (23 Mt CO_2-eq yr^{-1}), North America (49 Mt CO_2-eq yr^{-1}), and South America (12 Mt CO_2-eq yr^{-1}) that are in the same order of magnitude as established cities in Asia (50 Mt CO_2-eq yr^{-1}). Retrofit-oriented strategies targeting mid-development and established urban systems yield broadly applicable but individually modest mitigation across the Global North and middle-income economies. Third, Asia (379 Mt CO_2-eq yr^{-1}) dwarfs the contributions of Australia (5 Mt CO_2-eq yr^{-1}), Europe (31 Mt CO_2-eq yr^{-1}), and South America (35 Mt CO_2-eq yr^{-1}) by a factor of roughly 10–75.

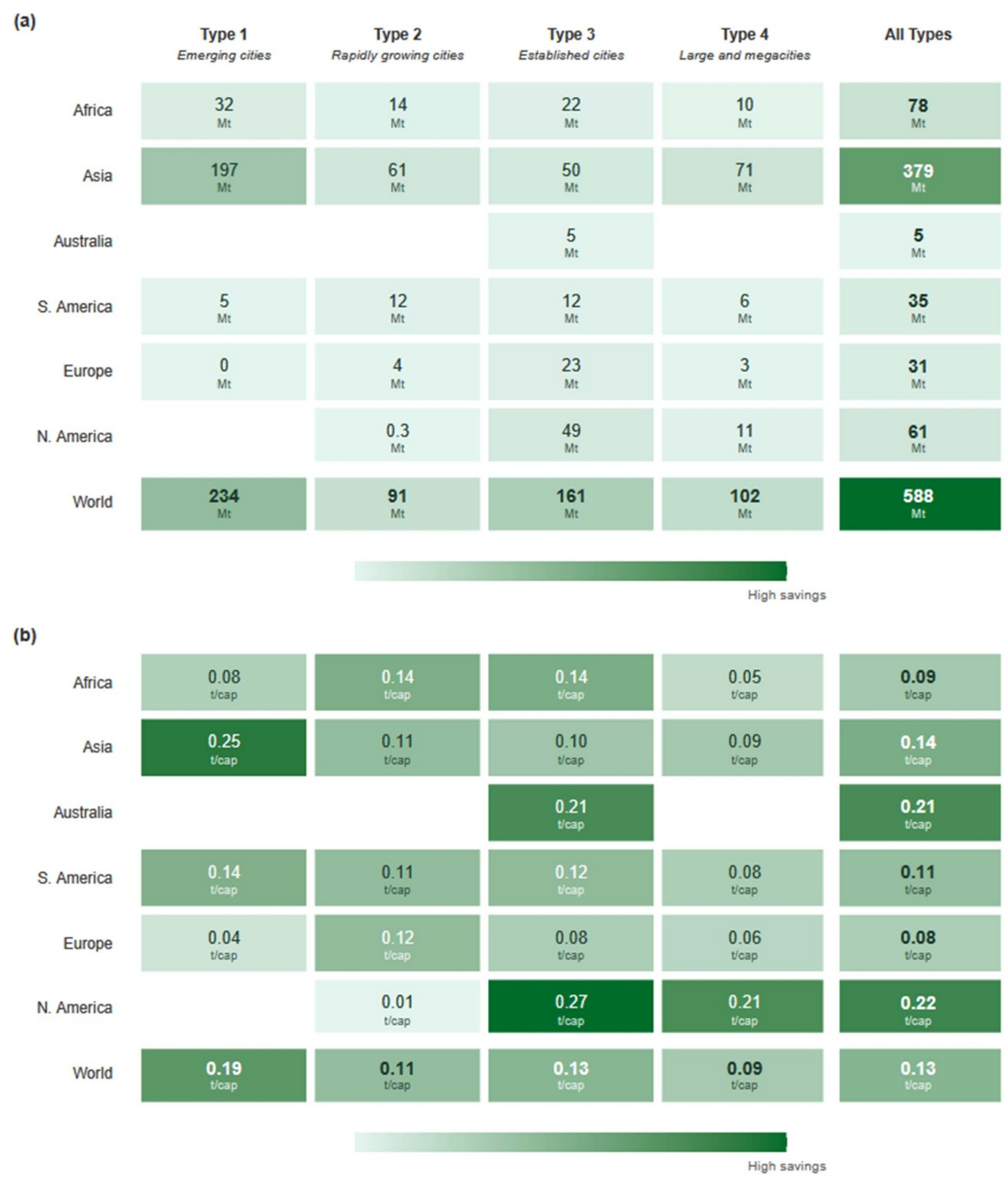

Figure 4. (a) Absolute reduction and per capita reduction (b) in GHG emissions by urban planning for 6 world regions (rows) and 4 types (columns). Last row includes types aggregated across regions, last column includes world regions aggregated across types.

Asia is where UP has the greatest impact through 2050 (albeit Africa is expected to overtake Asia after 2050 due to continuing population growth). A comparison with per capita reduction potentials (figure 4(b)) shows that Australia and North America, with moderate overall reduction potential, have high reduction potential if gauged by population.

3.3. Strategy specific contributions to urban transport GHG emission reduction by region

We also investigate the contribution of four different urban and transport planning strategies on emission reductions with resolution on different world regions (table 2).

We implemented each of the four UP strategies; transit-oriented development, densification, parking policy, and mixed-use development as stand-alone scenarios in MESSAGEix-Transport to assess their relative contribution to GHG emissions reduction. Across the four strategies assessed, ToD emerges as the single most effective land-use intervention, accounting for 37.8% of total projected reductions (83.09 Mt CO_2 yr^{-1} by 2050). Parking policy reform ranks second (28.2%; 61.94 Mt CO_2 yr^{-1}), followed by mixed-use development (MxD; 19.7%; 43.36 Mt CO_2 yr^{-1}) and densification (14.2%; 31.15 Mt CO_2 yr^{-1}).

Transit-oriented development particularly plays out in rapidly developing regions. Specifically, Asia

Table 2. Respective contributions of four urban and transport planning strategies to reduce intertemporal GHG emissions. Scenarios are modelled inside MESSAGEix-Transport and reductions are measured relative to the business as usual scenario (Mt CO_2 yr^{-1} by 2050). Values are shown as absolute reduction (Mt CO_2 yr^{-1}) with share of global total (219.54 Mt yr^{-1}) in parentheses. Bold values provide aggregrate measures.

Region	Densification	Transit-oriented Dev. (ToD)	Parking policy	Mixed use (MxD)	Region total
Africa	4.9 Mt (2.2%)	23.8 Mt (10.9%)	16.5 Mt (7.5%)	6.2 Mt (2.8%)	**51.5 Mt (23.5%)**
Asia	15.3 Mt (7.0%)	32.8 Mt (14.9%)	20.8 Mt (9.5%)	13.6 Mt (6.2%)	**82.5 Mt (37.6%)**
Australasia	0.2 Mt (0.1%)	1.8 Mt (0.8%)	0.7 Mt (0.3%)	2.2 Mt (1.0%)	**4.9 Mt (2.2%)**
C. & S. America	2.3 Mt (1.0%)	7.2 Mt (3.3%)	6.2 Mt (2.8%)	4.7 Mt (2.2%)	**20.5 Mt (9.3%)**
Europe	3.2 Mt (1.5%)	4.2 Mt (1.9%)	4.99 Mt (2.3%)	5.4 Mt (2.5%)	**17.8 Mt (8.1%)**
North America	5.2 Mt (2.4%)	13.2 Mt (6.0%)	12.7 Mt (5.8%)	11.12 Mt (5.1%)	**42.3 Mt (19.3%)**
Strategy Total	**31.1 Mt (14.2%)**	**83.1 Mt (37.8%)**	**61.9 Mt (28.2%)**	**43.4 Mt (19.7%)**	**219.5 Mt (100%)**.

contributes the largest share of total mitigation potential (37.6%; 82.53 Mt CO_2 yr^{-1}), driven primarily by ToD (32.79 Mt CO_2 yr^{-1}) and parking policy (20.77 Mt CO_2 yr^{-1}). Africa ranks second in absolute terms (51.48 Mt CO_2 yr^{-1}; 23.5%), with ToD alone responsible for 46.3% of the region's total, which is the highest intra-regional concentration observed across any region–strategy pairing. North America follows (42.34 Mt CO_2 yr^{-1}; 19.3%), with a comparatively even distribution across ToD, parking, and MxD.

Europe exhibits the most balanced strategy profile. Here GHG emission reductions are distributed across densification (17.9%), ToD (23.8%), parking (28.0%), and MxD (30.3%). This finding matches the observation that Europe is already largely urbanized and demographically consolidated. Accordingly, strategies that modify existing urban spaces are more effective than those related to planning new settlements. Paris serves here as a key example, where street space reallocation to pedestrians and cyclists, targeted towards improving quality of life, overturning modal shift patterns and thus reducing GHG emissions.

Australasia's contribution remains marginal in global terms (4.87 Mt CO_2 yr^{-1}; 2.2%). Mixed use development accounts for a disproportionately large intra-regional share (44.9%), motivating a larger shift in UP paradigm.

Overall, strategies that constrain car-dependent sprawl at the point of urban expansion (especially transit-oriented development) yield the greatest climate mitigation returns in high-growth regions, whereas incremental approaches such as densification and mixed use development contribute relatively more where cities are already substantially built out.

4. Discussion

We here do not consider Small Island Developing States, which have an overall miniscule contribution to GHG emissions in urban environments. Notably, Small Island Developing States often have high reliance on oil imports for powering their motorized transport. Reducing the need for oil, alongside electrification of their transport fleets, will result in improved public and private budgets in small islands. Decarbonization of national electricity grids will help to also further reduce the GHG emission footprint of electric vehicles. However, already now electric vehicles outcompete internal combustion engines even in coal-heavy jurisdictions (IEA 2024). With rapidly declining battery costs, solar PV coupled with short-term storage battery capacity is becoming the economically attractive choice (Vasdev 2026), making the decarbonization of power grids a relatively straightforward issue.

Our results reveal the importance of growing cities in Asia and Africa in using UP to achieve climate change mitigation. This does not absolve established cities in the Global North from their responsibility. As historical high emitters, they bear the brunt of responsibility for reducing GHG emissions quickly. As their urban form is mostly locked-in, these cities may need to rely on a different set of strategies, such as electrification of vehicle fleets, congestion charging, and retrofitting of buildings. That said, research shows that also established cities, such as Berlin, can reduce counterfactual project related (not city-wide) emissions by more than 40% in UP (Nachtigall *et al* 2025).

Low-carbon UP also does not need to be a burden for cities. To the contrary, cities possess local motivations to engage in low-carbon UP. First, less investments are needed into expansive infrastructures. More compact cities require less water infrastructure, road space, grid, and other infrastructure per capita (Bettencourt 2013), imposing lower aggregate public and infrastructure costs over time compared to BAU sprawled greenfield development. Compact development patterns in the United States have been estimated to reduce infrastructure capital expenditures by approximately 11%, road construction costs by 25%, and utility costs by up to 15% relative to sprawl (Burchell *et al* 2002). When accounting for infrastructure provision, public service delivery, traffic congestion, accident risk, and environmental externalities, sprawl imposes aggregate annual costs of USD 400–2000 billion across OECD economies (Litman 2015) (OECD: Organisation for Economic Co-operation and Development). These costs are paid by tax payers and the social sphere, but are not seen by private developers. Minimum parking requirements add between USD 5000 and USD 50 000 per space to development costs depending on construction style, thus subsidizing car use while increasing housing prices and suppressing urban density. Removal of minimum parking requirements has been shown to reduce development costs and increase housing supply in North American contexts (Shoup 2005, Manville 2013). ToD entails significant upfront public investment in transit infrastructure, which however also translates into substantial land value appreciation (10%–25% premiums within 400–800 metres of stations) that can be recycled to offset capital costs through tax increment financing and development levies or land taxation (Cervero *et al* 2004, Salon and Shewmake 2011). Mixed-use development similarly reduces vehicle kilometres travelled and associated infrastructure demand (Cervero and Kockelman 1997, Ewing and Cervero 2010), but is often delayed or stopped by single-use zoning, and lengthy permitting processes (Glaeser and Gyourko 2003). Overall, compact cities are deterred not by costs but by a gigantic market failure: the cost advantages of compact development are realized over multi-decadal timescales and accrue disproportionately to the public sector and society broadly, whereas private developers, undeterred by externalities, prefer greenfield sprawl (OECD 2012).

The effect of compactness affects not only energy use and GHG emissions directly. It also has systematic effects, both relevant for climate change and the well-being of citizens. On GHG emissions, citizens in denser urban environments travel more long-distance by aviation, an effect that can compensate or even override emission savings in mobility and housing (Czepkiewicz *et al* 2018); in cities that are greener, urbanites tend to fly less (Kinnunen *et al* 2026). Urban structure also influences well-being. For example, more compact cities with higher accessibility enable more active transport (walking, cycling, often in combination with PT), which generates high health benefits, especially for those not active otherwise (Woodcock *et al* 2013, Ahmad *et al* 2020). Cities also require less finance for fossil fuel imports and keep more resources for local economies (Soomauroo *et al* 2020). Moreover, spatial planning, particularly integrated spatial planning, is also a key mitigation strategy to reduce demand for cities with net-zero carbon ambitions (Seto *et al* 2021). Additional co-benefits include preserved surrounding natural capital, reduction in car ownership, and possibilities to reduce material use (Ramaswami *et al* 2023).

However, more compact development also encounters barriers and disadvantages. One disadvantage, detrimental to well-being, is that dense urban environments restrict opportunities for street trees, urban forests, and other urban green infrastructure that can help to moderate urban heat island effects (Erlwein and Pauleit 2021). A way out is to plan for star-shaped cities: ToD along linear corridors with urban parks in between transport axes (Pierer and Creutzig 2019); on the micro-level, urban green spaces can reduce heat exposure (Li and Zhou 2019). Another challenge is some jurisdictions and local opposition (Nimbyism) make it hard to densify existing urban structures. This is a political challenge that requires political talent and coalition building, possibly by associating compactification with novel benefits for residents.

The discussion on systematic and wider well-being effects points towards limitations of our study and directions for further research. Our analysis is not fine grained enough to quantitatively clarify how co-aligning well-being is best improved and how trade-offs are quantitatively mitigated, e.g. when densification and availability for green spaces become forces tearing into opposite directions. Cities like Singapore, Berlin, or Curitiba showcase that trade-offs can be managed, at least partially. Representing such strategies into integrated assessment modelling will be an interesting avenue to have cities' concerns adequately reflected also in global research on climate solutions.

5. Conclusion

This is the first paper that models the contribution of UP to climate change mitigation based on IAM infrastructure with enhanced and consistent representation of urban-related aspects and dynamics across transport and buildings through specialized sectoral models. We find that more compact cities can reduce GHG emissions in land transport and the building sector globally by 14% by 2050 compared to the baseline. Specific contributions result from reductions in building energy use, travel distance, modal share, and construction materials. Building construction savings and reduction in car use provide the most relevant contributions.

A preceding paper also computed an urban mitigation wedge (Creutzig *et al* 2015a). That paper used econometric analysis to identify the relevance of population density and fuel prices for urban energy use and GHG emissions, including both transport and building sector. It finds a potential reduction in energy by 26% between 2005 and 2050. A key difference is the longer timeline (45 years, instead of 25 years, allowing for higher counterfactual reductions). Another key difference is that in this paper, we gauge transport and building sector contribution with an IAM, rather than using the econometric approach used in the previous study.

All types of cities can contribute at least 20 Mt yr^{-1} via UP, but emerging cities can contribute more than the other types. Here, carbon lock-in can be prevented. Among all world regions, Asia dominates UP mitigation potential by 2050, specifically South East Asia and South Asia. Sub-Saharan Africa also shows high potential, and due to population growth, Africa is expected to become the most critical world region in the second half of this century.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Supplementary data available at https://doi.org/10.1088/1748-9326/ae83d1/data1.

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