Urban Carbon Neutrality: Accounting Boundaries, Sectoral Pathways and the Governance Gap

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Abstract

Cities concentrate people, capital and energy demand, and they are at once the principal source of global greenhouse gas emissions and the most tractable scale at which deep decarbonisation can be organised. Yet the proliferation of municipal net-zero pledges has outpaced the analytical and institutional machinery needed to make them credible. This article synthesises literature on urban carbon neutrality along three axes: the boundary within which a city counts its emissions; the sectoral pathways through which abatement is expected; and the governance, finance and equity conditions under which commitments become outcomes. It argues that credibility depends less on the ambition of headline targets than on three unglamorous conditions: transparent and comparable boundaries, implementation capacity backed by stable municipal finance, and explicit treatment of distributional incidence. It concludes with a research agenda oriented towards open, harmonised data, systems-level evaluation and distributional analysis that treats equity as a design parameter rather than an afterthought.

Keywords

Urban carbon neutrality, Consumption-based accounting, Decarbonisation pathways, Urban energy transitions, Climate governance, Distributive justice

Introduction

The twenty-first century is an urban century in a demographic sense that is now largely settled. Just over half of the world's population lived in urban areas in 2018, and that share is projected to approach two-thirds by 2050 [1]. Urban settlements are associated with roughly three-quarters of global energy-related carbon dioxide emissions, reflecting the density of buildings, mobility systems, industrial activity and consumption that cities host [2]. The net-zero target embedded in the Paris Agreement therefore cannot be met unless urban systems are decarbonised, and cities offer an unusually dense set of intervention points: building codes, land-use planning, transit, procurement, waste infrastructure and, in many jurisdictions, energy and mobility powers.

A policy consensus has crystallised with remarkable speed. Several hundred municipal governments, together with regional authorities and corporate actors, have adopted net-zero or climate-neutrality targets, most dated between 2030 and 2050 [3].

The vocabulary of the "net-zero city" has migrated from activist manifestos into municipal statutes, bond prospectuses and mayoral platforms. This diffusion is a genuine political achievement, but it is not evidence of emissions reduction. The gap between announcing a target and delivering measurable abatement remains the central problem of urban climate policy, and it is a problem of accounting, implementation and distribution as much as of technology or cost.

Three features explain why that gap persists. The first is boundary ambiguity. A city may report emissions produced within its perimeter, emissions embodied in what its residents consume, or some hybrid of the two, and the resulting figures can differ by a factor of two or more for affluent municipalities [4]. These inventories answer different questions, support different policies and are rarely reconciled. The second is the mismatch between sectoral interventions and systems-level outcomes. Buildings, transport, power, waste and land use are administered by different departments and financed through different instruments, and evaluations typically assess each measure in isolation, whereas outcomes depend on interaction: electrifying heating

reduces emissions only if supply decarbonises, and densification reduces transport emissions only if accompanied by transit capacity and parking reform. Sectoral successes can therefore coexist with stagnant urban emissions. The third is the governance and fiscal context. Municipalities rarely control the determinants of their own emissions, since power systems, vehicle standards, building codes and carbon pricing are set nationally, while infrastructure costs fall on local budgets. Cities with weak credit ratings face borrowing costs that make long-lived low-carbon investment unaffordable irrespective of its social return, and the distributional incidence of policy is frequently treated as an implementation detail rather than a design constraint [5]. The article addresses these features in turn. Section 2 explains why carbon lock-in is an infrastructural and institutional phenomenon rather than a purely technological one. Section 3 compares territorial, consumption-based and hybrid accounting and argues that boundary transparency, not boundary choice, is the binding requirement for credible claims. Section 4 reviews sectoral evidence with attention to sequencing and interaction. Section 5 examines the governance, financing and measurement architecture that determines whether plans become outcomes; Section 6 considers justice; and Section 7 sets out a research agenda. The contribution is connective rather than empirical, linking literatures on urban energy modelling, carbon accounting, public administration and environmental justice.

Cities as systems of flows and lock-in

The urban metabolism framing

Analytically, a city is not a place but a process: a densely organised arrangement of flows through which energy, materials, food and people are imported and transformed, and through which wastes and emissions are exported. This metabolism framing has two consequences for carbon policy. It locates emissions at the point of conversion and consumption rather than at the point of jurisdiction, and it makes visible the dependencies that determine a city's abatement options. A municipality that imports all of its electricity can electrify transport and heating, but it cannot determine the carbon intensity of the power it consumes; a city that has outsourced its manufacturing can reduce territorial emissions through deindustrialisation without any corresponding global benefit. Per-capita emissions also vary widely among cities with similar incomes, reflecting the composition of economic activity, grid intensity, building stock age, mode share and household consumption. Comparative work on more than thirteen thousand cities found that consumption-based footprints rise with income and that the gap between accounting approaches widens in wealthier, service-oriented economies. A city's emission profile is thus partly a function of its position in wider supply chains, which municipal policy can influence only indirectly.

Carbon lock-in as an infrastructural condition

The second conceptual anchor is carbon lock-in. Long-lived infrastructure, buildings, road networks, district heating systems and land-use patterns commit a city to particular emissions for the lifetime of the assets. The concept, originally developed to explain the persistence of fossil energy systems despite cheaper alternatives, has been extended to urban form and to the institutions that reproduce it [6]. Three mechanisms are involved. Infrastructural lock-in arises because assets are expensive, durable and physically embedded, so replacing them is a discrete and financially demanding act. Institutional lock-in arises because regulations, professional standards, utility business models and budget rules are calibrated to the incumbent system, so that alternatives face procedural rather than purely economic obstacles. Behavioural lock-in arises because routines of commuting, heating and consumption are organised around existing systems and are costly to renegotiate. Because infrastructure turns over slowly, the 2020s constitute a decisive window: assets built now will still operate in 2050, when most targets fall due. Modelling of urban mitigation potentials finds that economically attractive abatement before mid-century depends on avoiding new high-carbon assets rather than retrofitting them later [7]. Sequencing therefore matters more than the aggregate cost curve.

What urban net zero can mean

The term net zero also requires definitional care. In its coherent form it denotes a state in which emissions are reduced to the minimum consistent with physical constraints and any residual is balanced by durable removals. Applied to a city, the concept is ambiguous along three dimensions: the gases and scopes covered, the treatment of emissions generated outside the boundary on the city's behalf, and the permissibility of

offsets. A municipal target covering only carbon dioxide from in-boundary combustion, with residual emissions balanced by distant forestry credits, is not equivalent to one covering all gases across consumption, even if both are labelled net zero. Credibility therefore depends on specification: which scopes, which gases, which removals, and which entity is accountable for what lies outside the perimeter.

Measuring urban emissions: Three boundaries

Territorial inventories

The dominant approach remains the territorial, or production-based, inventory, in which emissions are attributed to the jurisdiction where they physically occur, typically covering direct combustion and, under the widely adopted Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, indirect emissions from grid electricity consumed locally [8]. The protocol's sectoral structure mirrors municipal responsibilities and therefore aligns accounting with the levers a city controls. Their limitations are equally structural. They exclude emissions embodied in imported goods, food and materials, count emissions from exported electricity or manufactured products as the exporting jurisdiction's responsibility, and are vulnerable to boundary arbitrage: a city can record progress by relocating a power plant or landfill across its border, with no change in global emissions.

Consumption-based and scope 3 accounting

Consumption-based inventories address this by allocating emissions to the final demand that drives them, using environmentally extended multi-regional input-output models to trace supply chains. Applied at urban scale, they show that affluent cities typically carry footprints substantially larger than their territorial accounts, with the difference concentrated in construction materials, food, vehicles, electronics and travel. The methodological costs are significant: multi-regional input-output estimates depend on model assumptions, sectoral aggregation and imperfect trade data, and their uncertainty is larger than that of territorial inventories, particularly for cities with weak statistical infrastructure.

Results are published with a lag, which limits their use in annual monitoring, and the accounts do not map neatly onto municipal authority, since a city cannot regulate emissions embedded in imported steel, although it can specify low-carbon materials in public projects and shape consumption through procurement and planning.

Comparability, transparency and the data gap

The practical conclusion is not that one boundary should be universally adopted but that claims should be explicit about which boundary they use and why. Cities should report territorial and consumption-based estimates side by side for benchmark years, so that outsourcing and displacement are visible; targets should specify scope, gas coverage and the treatment of removals in a form permitting third-party verification; and inventory data and emission factors should be published in machine-readable form, since closed proprietary inventories cannot be audited.

The data gap between the Global North and South is the most consequential weakness in this landscape. Many rapidly growing cities lack the metered energy data, vehicle registries, waste records and institutional continuity needed for reliable inventories, and international datasets frequently downscale national totals using proxies that misrepresent local conditions. Satellite observations can fill some gaps, but they detect combustion rather than measure it and cannot substitute for activity data in the buildings and waste sectors. Investment in municipal statistical capacity is therefore a climate intervention in its own right, and one that carbon finance has been reluctant to fund.

Sectoral pathways and their interactions

Buildings

Buildings account for roughly a third of global final energy consumption and a comparable share of energy-related emissions, and in many cities they are the largest single source. The mitigation portfolio is well understood: improve the thermal performance of the envelope, raise equipment efficiency, electrify heating and cooling through heat pumps, and reduce the embodied carbon of materials. What is less understood is the rate at which the stock can be transformed. New construction is a small fraction of the stock in mature cities, so decarbonisation depends on deep retrofits at a pace no jurisdiction has achieved; retrofit rates in most industrialised countries remain below one per cent annually, against the two to three per cent implied by mid-century targets.

Three obstacles recur. The first is the split incentive between landlords, who bear the capital cost, and tenants,

who capture the savings, which regulation addresses only partially through minimum standards and disclosure. Second is the sequencing of electrification and supply decarbonisation: heat pumps reduce emissions only to the extent that the network is clean, and poorly sequenced programmes can raise peak demand and system cost. Third is embodied carbon, which becomes proportionally more important as operational emissions fall and is poorly covered by codes regulating performance in use rather than whole-life carbon.

Mobility and transport

Transport typically accounts for a fifth to a quarter of urban emissions. The policy hierarchy, avoid, shift, improve, remains sound: avoid travel through compact mixed-use development; shift to public transport, walking and cycling; improve vehicles through electrification. The evidence is uneven. Electrification of cars and buses is proceeding faster than most forecasts anticipated and delivers large life-cycle savings where grids are relatively clean, yet it does not resolve congestion, road-space allocation, particulate pollution from tyres and brakes, or the equity problems created by charging infrastructure that serves affluent early adopters first.

Compact development has the largest long-run effect, because urban form determines travel distances and mode choices for generations, but the relationship is contingent: density without transit capacity, parking reform and street design produces congestion rather than shorter trips. The “fifteen-minute city” has been widely adopted as a heuristic, but it assumes homogeneous neighbourhoods and overlooks workers whose jobs cannot be localised. Freight and servicing remain under-addressed despite a growing share of vehicle kilometres.

Power, heat and networks

Urban power and heat systems are where local action and system-scale decarbonisation interact most visibly. Cities can deploy rooftop solar, facilitate district heating and cooling and encourage demand flexibility, but the carbon intensity of their electricity is set by the regional grid and national planning. Municipal renewable procurement, through power purchase agreements or participation in generation assets, can accelerate additions, and aggregating municipal demand has proved effective in creating bankable projects. District energy is a particular opportunity in dense settlements, where industrial waste heat, geothermal resources and large heat pumps can displace fossil fuels at lower cost than building-by-building electrification. The technology is mature; the obstacles are institutional, since networks require long concessions, coordinated excavation and customers willing to accept monopoly supply.

Waste, materials and circularity

Waste is the smallest conventional sector but the one with the highest ratio of co-benefits to cost. Landfill methane is a potent short-lived forcer, and separate collection of organic waste with anaerobic digestion or composting is among the cheapest abatement available to municipalities. Construction and demolition waste offers larger volumes and greater circularity potential where recycled aggregates and modular design reduce demand for virgin cement and steel, the materials responsible for much of the embodied urban footprint. The governance challenge is that of the informal economy as much as of engineering: in many cities in the Global South, collection and recycling are performed by informal workers whose livelihoods depend on the streams that formal circular-economy policies seek to capture. Integration through contracts or cooperatives tends to improve both recovery rates and working conditions, whereas exclusion produces displacement without environmental gain.

Conclusion

Urban vegetation, soils and water bodies sequester carbon, cool the local climate and manage stormwater, but the quantities are modest relative to urban emissions, typically a small percentage of the total. This matters for accounting integrity: sequestration should be reported as a co-benefit, not used to offset continued fossil emissions, since crediting urban sinks against gross emissions usually yields an accounting claim rather than a climate outcome. The more defensible rationale for green infrastructure is adaptation and liveability: trees, parks and blue corridors reduce heat exposure, which is increasingly lethal in dense neighbourhoods with limited cooling, and deliver health and biodiversity benefits that carbon metrics do not capture.

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Conflicts of Interest

The author declares no conflict of interest.

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