Title	How can cities achieve accelerated systemic decarbonization? Analysis of six frontrunner cities
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How can cities achieve accelerated systemic decarbonization? Analysis of six frontrunner cities

Abstract

Globally, many cities have pledged to reach net zero emissions by mid-century and formulated climate action plans (CAPs) to pursue this goal. Attainment of net zero requires accelerated systemic decarbonization measures to catalyze fundamental changes across multiple societal systems simultaneously. Yet the extant literature has not conceptually clarified conditions leading to accelerated systemic decarbonization in cities. This research therefore aims to: (1) conceptualize strategies that contribute to accelerated systemic decarbonization at the sub-national level and develop a framework for empirically identifying these; and (2) assess the extent to which CAPs in cities known for progressive climate policies embody these characteristics. This involved examination of evidence from CAPs and related documents in six cities: Copenhagen, Leeds, Oslo, San Francisco, Australian Capital Territory and Kyoto. Findings show that San Francisco's climate actions are the most indicative of accelerated systemic decarbonization. In other cities, although many ingredients for accelerated systemic decarbonization are in place, several missed opportunities to achieve more rapid and transformative decarbonization outcomes were identified. These include lack of consideration of scope 3 emissions and limited participatory governance measures as well as absence of economic planning, climate budgets and financial indicators to estimate the benefits or costs of various climate-mitigation actions.

Keywords: accelerated decarbonization, systemic change, city climate policy, climate action plans, emission reduction measures, net zero targets

List of Acronyms:

ACT – Australian Capital Territory
CAP – Climate Action Plan
CO2 – Carbon Dioxide
ERMs – Emission Reduction Measures
EVs – Electric Vehicles

IEA – International Energy Agency

ICLEI – International Council for Local Environmental Initiatives

IPPC – Intergovernmental Panel on Climate Change

GHG – Greenhouse Gases

UNEP – United Nations Environment Programme

Section 1. Introduction

Cities are responsible for over 70% of global energy-related CO_2 emissions and play a central role in the pursuit of rapid decarbonization (Bazaz et al., 2018; Floater et al., 2014; IPCC, 2014; Seto et al., 2014; Van der Heijden, 2019). With direct control over local regulations, cities are often able to implement more ambitious policies than their national counterparts (Hsu et al., 2020; Nakazawa et al., 2023; Wright, 2021). To harness this potential for urban climate leadership, several global networks seek to connect otherwise dispersed efforts to stimulate cross-learning and synergies around the practice of decarbonization; these include the Carbon Neutral Cities Alliance, Net Zero Cities by the European Union, C40 Cities Climate Leadership Group and Cities Race to Zero by C40, the Global Covenant of Mayors, and the International Council for Local Environmental Initiatives (ICLEI) (Heikkinen et al., 2020).

City-level responses to the climate crisis continue to attract attention from scholars (Broto, 2017; Davidson et al., 2020; Holtz et al., 2018; Seto et al., 2021; Van der Heijden, 2019) and policymakers (UNEP, 2022; World Bank Group, 2021). Climate action plans (CAPs) have become a pivotal tool employed by cities in their climate mitigation efforts. CAPs fall into two categories: (1) plans focused on reducing emissions from local government operations (so-called corporate CAPs), and (2) plans addressing the entire city (so-called community-wide or community-scale CAPs), which seek to cut emissions from industrial and societal activities (e.g., built environment, manufacturing, heat generation, transportation) as well as from the production and consumption of goods and services outside a city's geographic boundaries (Chen et al., 2019; Linton et al., 2022; Ramaswami et al., 2021; Tong & Ramaswami, 2022). CAPs embody a complex and diverse mosaic of local responses to climate change, with some being more ambitious and successful than others (Deetjen et al., 2018; Dhakal & Ruth, 2017; Linton et al., 2020; Markolf et al., 2020). Given the pressing need for rapid and deep decarbonization beyond local government operations, this article focuses on

CAPs that holistically address emission reductions for the entire city—the so-called community-wide CAPs.

As cities are increasingly expected to contribute to the global goal of reaching carbon neutrality by mid-century, there is growing emphasis on the need for faster-acting and more systemic approaches (Chapman et al., 2016; Ramaswami et al., 2021). Indeed, accelerating sustainability and decarbonization transitions may require a focus on achieving whole systems change, shifting away from incrementalism (Markard et al., 2020; McPhearson et al., 2021; IPCC, 2023). The notion of "whole systems change" points to the need to trigger fundamental, simultaneous, and self-reinforcing changes to, and innovations in, large-scale systems, including energy, mobility, food, water, and waste management (Meadowcroft et al., 2021). It recognizes that cities are part of wider systems of consumption and production and are embedded in regional, national, and global infrastructure systems, along with multilevel governance systems (Holtz et al., 2018). Decarbonization of these systems requires strategies to: (1) reconfigure mobility; (2) transform the built environment (reducing urban energy and material demands); (3) shift energy systems away from fossil fuels; and (4) realign food systems, waste, and water management toward net zero goals. In some contexts, addressing residual emissions will require compensation through technological or nature-based carbon removal methods (Dong & He, 2023). Therefore, the next challenging step in the evolution of CAPs can be understood as shifting from focused acceleration that concentrates resources on a narrow spectrum of activities and sectors offering a comparatively high return in terms of emission reductions (C40 Cities, 2017) towards more holistic and interconnected approaches.

Thus, strategies to achieve both *accelerated* and *systemic* decarbonization are expected to become a defining feature of the most ambitious CAPs by cities around the world (Echeverri, 2018; One Earth, 2022). Despite this, the burgeoning literature on urban climate governance (Holtz et al., 2018; Seto et al., 2021; Van der Heijden, 2018) is yet to conceptually clarify the conditions expected to lead to accelerated and systemic city-level decarbonization. There is a similar dearth of knowledge on whether various decarbonization actions taken by city governments around the world reflect these conditions (Broto, 2017; Davidson et al., 2020).

Against this backdrop, this empirical article has two objectives: (1) conceptualize strategies that contribute to accelerated systemic decarbonization at the sub-national level and develop a framework for empirically identifying these; and (2) assess the extent to which CAPs from a cohort of cities known for progressive climate policies embody these characteristics. Six cities were selected for analysis: Copenhagen, Leeds, Oslo, San Francisco, Australian Capital Territory and Kyoto. Listed in order of ambition based on the target year for reaching net zero emissions, this cohort of cities encompasses diverse geographical and jurisdictional contexts (Australian Capital Territory is a federal territory rather than a city) and contrasting decarbonization schedules, with net zero targets ranging from 2025 to 2050. This sample thus provides an ideal opportunity to determine the extent to which policy actions of cities at the leading edge of climate mitigation in industrialized economies are reflective of accelerated systemic decarbonization.

In what follows, Section 2 outlines the contribution of this research while Section 3 conceptualizes the defining characteristics of accelerated systemic decarbonization. Section 4 presents the research design. An analytical framework is then proposed as a tool for assessing the extent to which city CAPs embody these characteristics. The section also introduces data sources, including more details on the rationale underpinning case study selection. Section 5 presents the socio-demographic characteristics of the cases as well as the historical and projected emissions-reduction pathways to net zero for each city. The analytical framework is applied in Section 6, which examines the extent to which each city's climate-mitigation response, reflected in its CAPs, can be considered accelerated and systemic. Section 7 discusses key results, situating them in the broader literature. Finally, Section 8 concludes by summarizing takeaway messages, identifying key limitations, and proposing avenues for future research.

Section 2. Research contribution and originality

There is rich theoretical pluralism and methodological diversity in the existing research on urban sustainability and climate mitigation. One significant body of scholarship focuses on specific measures or targets like the adoption rate for renewable energy, enhancement of building energy efficiency, or just sustainability (Broto & Westman, 2017; Linton et al., 2022; Trencher & Van der Heidjen, 2019). From a meta-perspective, another research area includes data collation and analysis of urban climate planning across a wide range of cities. Several studies identify the extent of CAP adoption, common formats and measures proposed, and extract key lessons on the state of climate mitigation and adaptation (Aboagye & Sharifi, 2023; Lamb et al., 2019; Sethi et al., 2020).

Extensive research has also been undertaken on the sectoral dimensions of urban climate mitigation covering, for example, energy infrastructure, mobility, and households (Chang et al., 2022; de Chalender et al., 2019; Dewi et al., 2023; Jiang et al., 2020; Stankuniene et al., 2020; Vallejo-Diaz et al., 2022; Yang et al., 2021). An emerging area of research relates to the potential for smart cities and the digital economy to contribute to urban decarbonization (Feng et al., 2022; Kinelski, 2022; Kobashi et al., 2020; Wang et al., 2023; Yu et al., 2023).

Other studies report on the multiple barriers to urban decarbonization. These typically arise from policy and technical difficulties when formulating, implementing, and monitoring Emissions Reduction Measures (ERMs) (Carloni & Green, 2017; Dahal & Niemeila, 2017; Eisenack & Roggero, 2022; Linton et al., 2020; 2022). Research on socio-technical transitions has identified other structural obstacles to urban decarbonization (Geels et al., 2017). For instance, city governments have limited regulatory control over carbon-intensive, hard-to-abate heavy industries like iron, steel, cement, and chemicals since these tend to fall under the remit of national governments and private firms (Battaille, 2020). Similarly, most cities lack direct authority over power generation. As a result, city-level decarbonization ambitions can be undermined by electricity utilities' failure to adopt zero-carbon energy portfolios (Alova, 2020).

Research has also highlighted how urban decarbonization may be further curtailed by city governments' inability to effectively engage communities and other local stakeholders in the pursuit of accelerated net zero targets (Fraser et al., 2020)—especially when this requires tackling individual lifestyles and consumption patterns (Lunetto et al., 2022; Truong et al., 2022). Mobility is another area that poses considerable challenges for urban decarbonization. Cities can provide incentives like subsidies and free parking, but the speed of electric vehicle (EV) growth is often determined by national-level policies as much as by the broader preferences of automakers and consumers. Though electric drivetrains make up a growing share of vehicle sales, rising 60% in 2022 relative to the previous year, the global on-road stock is still dominated by vehicles with internal combustion engines (IEA, 2023). Likewise, passenger and freight-travel patterns have been shown to be primarily shaped by decisions outside the purview of municipalities (Jones et al., 2021).

In this context, this study makes two key contributions. First, theoretically, an analytical framework is postulated that enables comparative evaluation of decarbonization strategies in city-level CAPs. This heuristic contributes to the rich literature on urban decarbonization and socio-technical transitions, which is yet to conceptualize and define features of accelerated systemic decarbonization at the city level. Second, empirically, the analysis builds an original dataset that synthesizes the core components of each city's CAPs and its associated climate actions, contributing to growing interest in the range of actions taken by cities towards net zero goals (Davidson et al., 2020; Seto et al., 2021). This dataset provides a structured means of identifying and comparing a broad range of strategies and conditions expected to determine the effectiveness of climate mitigation outcomes. Application of this framework can assist stakeholders in the identification of whether a set of strategies widely regarded as important contributors to achieving accelerated systemic decarbonization are present in climate actions of other cities or urban regions.

Section 3. Context for accelerated systemic decarbonization

Until recently, academic literature framed decarbonization pathways as long-term transitions resulting from incremental changes in socio-technical systems. These transitions would reduce greenhouse gas (GHG) emissions gradually over many decades, reaching zero emissions on a net basis (i.e., net zero or climate neutrality) by around 2100 (Akashi & Hanaoka, 2012; Bailey, 2017; Loftus et al., 2015; Smil, 2010). In recent years, countries and organizations have shifted to aim at achieving net zero emissions several decades earlier. 2050 has emerged as a global norm pursuant to the objective of the Paris Agreement, ratified in 2016, which seeks to limit global warming to 1.5°C (Black et al., 2021). The increasing emphasis on accelerated decarbonization gained traction with the IPCC's Special Report in 2018, which specified an interim target of cutting emissions by 45% by 2030 (IPCC, 2018). However, even this may be too late. Calls are mounting for accelerated and systemic decarbonization, including measures to phase out fossil fuels (Calverley & Anderson, 2022; IPCC, 2023; Trout et al., 2022; UNEP, 2022). These pressures to pursue accelerated decarbonization are increasingly evident at multiple levels (Griffith, 2021; Phadke et al., 2020; Rockström et al., 2017; UNEP, 2022). For example, several ambitious proposals have emerged in the United States, designed to re-engineer the country's energy system to achieve net zero by the mid-2030s (Arbib et al., 2021; Griffith et al., 2020a; 2020b; Phadke et al., 2020). Meanwhile, a roadmap to net zero by the International Energy Agency calls for a completely decarbonized electricity sector in advanced economies by 2035 along with no more sales of gasoline vehicles (IEA, 2023).

The momentum to pursue accelerated decarbonization is also gaining traction at the level of cities, with many pledging to achieve net zero before or by 2050 (Bery & Haddad, 2022). Without more ambitious measures, however, urban-based emissions are projected to increase globally by 38%

between 2020 and 2050 (IPCC, 2022). In response, a "Cities Race to Zero" campaign organized by local government networks—including C40 Cities, ICLEI, United Cities and Local Governments, and the Global Covenant of Mayors for Climate and Energy—is mobilizing a cohort of cities around the shared goal of reaching net zero emissions by the 2040s or sooner (Global Commons Alliance, 2020). Nevertheless, despite the intensifying ambitions of many cities, and high expectations for their contribution to global climate mitigation, cautious optimism may be warranted. Research from the US, for instance, indicates that even if net zero were reached well before mid-century in the country's 100 largest cities, cumulative emissions reduction would still fall short of what is required to limit warming to 1.5°C globally (Markolf et al., 2020).

In this context, pursuit of accelerated systemic decarbonization, even for the most progressive cities, requires multiple, fundamental, and cross-cutting actions to trigger the reconfiguration of interlinked technological, infrastructural, and societal systems. At the same time, dominant approaches to governing social, economic, and environmental affairs must be transformed (Janssen et al., 2022; Luque-Ayala et al., 2018; UNEP, 2022). This points to the need for systemic approaches to decarbonization that move beyond reliance on a narrow set of policy and technical measures (Berglund & Bailey, 2022; McPhearson et al., 2021). Though challenging for urban policymakers, a systems approach ideally mobilizes and integrates otherwise dispersed climate-mitigation actions. It emphasizes establishing interconnections and synergies between institutions, technologies, infrastructure, and natural systems, while creating co-benefits for health, welfare, and well-being (Chapman et al., 2016).

Outside urban climate governance, several strands of literature concur that fundamental, cross-cutting change is essential for responding to the magnitude of the climate crisis and contemporary sustainability challenges. Consider, for instance, calls for a "just transition" by proponents of radical system change (Abram et al., 2022; Beer, 2022; Stuart et al., 2022) or the literature on socio-technical transitions (Geels et al., 2017; Markard et al., 2020; Meadowcroft et al., 2021). The notion of systemic change also resonates well with scholarship on technology innovation systems. This work shows how barriers to technology diffusion are systemic—formed by interactions across cross-cutting social, economic, political, and technological systems—and calls for coordinated and systemic countermeasures (Jacobsson & Bergek, 2011; Wesseling & Van der Vooren, 2017; Woolthuis et al., 2005).

Section 4. Methods

4.1 Research design

The research design underpinning this study is summarized in **Figure 1**. The approach essentially involved five interconnected steps: (1) identify descriptions in academic and grey literature of strategies that contribute to accelerated and/or systemic decarbonization, (2) distil these into sets of strategies and develop indicators to identify their existence in city CAPs and related policy documents; (3) select a group of frontrunner cities for analysis and collecting data, (4) analyze data and code the degree to which these indicators were met, and finally, (5) identify common patterns and trends across cities. In addition, to deepen understanding of the decarbonization speed in each city, the analysis also produced visualizations of required pathways to net zero.

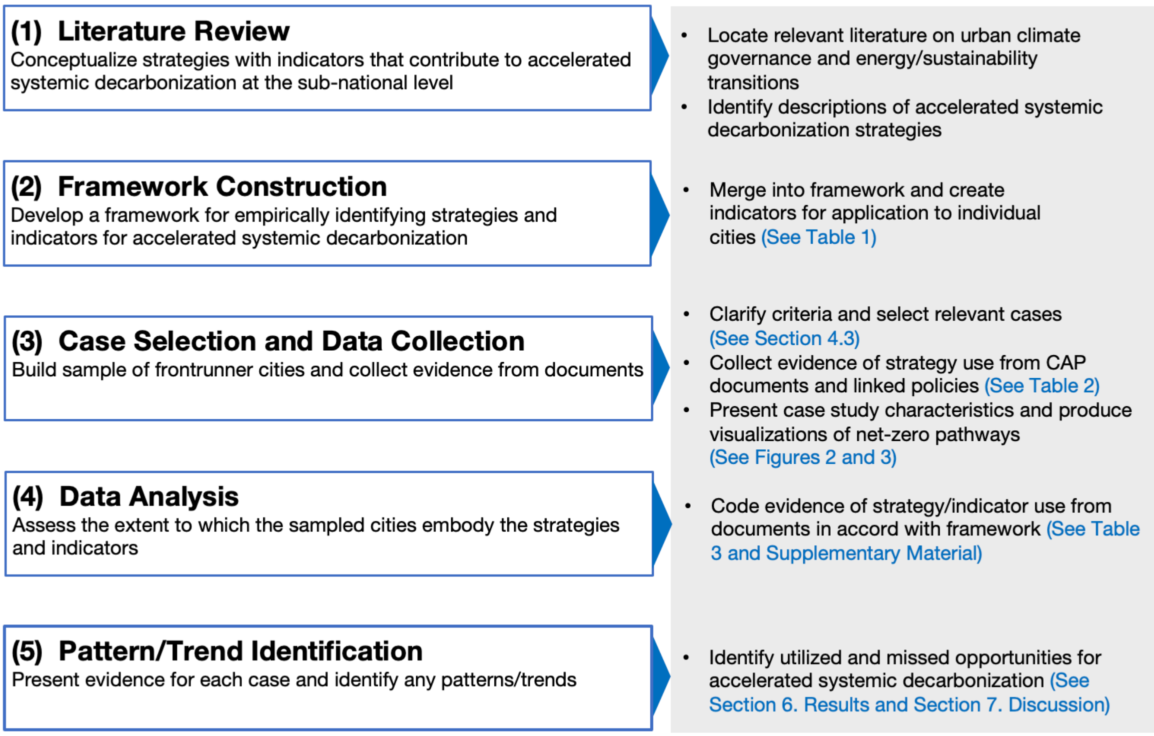


Figure 1. Summary of Research Design

4.2 Analytical framework for accelerated systemic decarbonization

Table 1 presents the framework developed to identify the existence of strategies expected to contribute to accelerated and systemic decarbonization in cities. These strategies are articulated based on the results of a targeted literature review. Relevant literature was systematically identified through keyword searches on Scopus and Google Scholar using various combinations that reflect the context (climate, decarbonization), geographic scale (city, municipality, urban), action (strategies, plans, mitigation), and rapid or systemic change (emergency, transition, innovation, systems). Studies were prioritized in academic fields such as climate governance, innovation management, sustainability transitions, energy policy, and urban studies.

To distill strategies for achieving accelerated and systemic decarbonization from the surveyed literature, a cloud-based spreadsheet was created and used to compile descriptions of various strategies from the identified studies. Tentative code names were assigned to each to reflect the measures discussed. After distilling a set of the most discussed strategies and principles, the codes and conceptions for each category were fine-tuned, merged when necessary, and re-checked with the literature. Following the approach of other studies (Luederitz et al., 2017; Trencher et al., 2021; Wolfram, 2016), specific indicators (framed as yes/no questions) were then created to operationalize the goal of empirically applying the framework to a set of cities and using it to compare the decarbonization actions described in CAPs. The framework serves the specific purpose of application with empirical data and provides a practical tool to guide policymaking and evaluation.

The emergent framework consists of four sets of broad strategies (S1–S4) and fourteen specific indicators discussed below.

(S1) Approach to Target-Setting: A robust approach to setting emission-reduction targets, in line with the latest scientific knowledge and international best practices, has the potential to support accelerated decarbonization. A precondition of robustness is transparency around the type of ERMs adopted, the scope of emissions addressed, the types of data used, and underpinning assumptions. Satisfying these conditions can raise trust among local stakeholders and facilitate third-party verification of progress towards targets (Carloni & Green, 2017). Such an approach to target-setting allows benchmarking against the latest scientific consensus on how best to measure urban carbon emissions, what carbon analytics are required, and how to evaluate the effectiveness of mitigation actions (Ramaswami et al., 2021). This strategy distinguishes between production-related emissions within the city's geographical boundaries (scope 1 and 2) and consumption-based and out-of-boundary emissions (scope 3). Including the latter increases the magnitude of a city's GHG emissions, spurring the need for wider decarbonization actions. This indicator recognizes the growing emphasis on including scope 3 emissions within urban climate governance (C40 Cities, 2018; Dahal & Niemelä, 2017) and the tendency for most of a city's carbon and environmental footprint to be embedded in imported resources, energy, and products (Chen et al., 2019).

(S2) Political Enabling Environment: A climate emergency declaration, when properly implemented, can create new policy frameworks and governance structures while justifying rapid, ambitious, and transformative actions (Davidson et al., 2020). Moreover, emergency situations can accelerate socio-technical transitions (Sovacool, 2016). Related to this, innovations such as citizen juries, assemblies and participatory budgeting can enhance societal engagement with CAPs, helping mobilize socially relevant forms of intelligence that are needed to govern low-carbon transitions (Chilvers et al., 2021).

(S3) Comprehensive Implementation Measures: The magnitude of the climate crisis requires holistic responses that catalyze rapid, wide-reaching, and transformative change across diverse sectors (McPhearson et al., 2021; Sethi et al., 2020). As renewable-energy installations multiply across urban areas, and as cities increasingly rely on greenspaces for carbon sequestration, there is a need to avoid conflicts and ensure harmony between policies for spatial planning, land use, and climate mitigation (Capellán-Pérez et al., 2017; Ravetz et al., 2021). Cities are also expected to tackle transboundary emissions sources such as power generation, long-distance transport, and waste management, which often lie outside traditional jurisdictions (Chavez & Ramaswami, 2011; Tong & Ramaswami, 2022). Reaching net zero requires decarbonizing through both supply-side and demand-side solutions (Axsen et al., 2020; Sethi et al., 2020). This necessitates not only multiple and heterogeneous interventions (Lamb et al., 2019; Sethi et al., 2020) but complementary structural transformations, with measures targeting lifestyles and consumer behavior also contributing to effective climate mitigation (Bailey, 2017; Lunetto et al., 2022; Markard et al., 2020). Rapidly realizing such deep-cutting transformations may depend on the presence of policies that complement innovation by deliberately attempting to downscale or phase out emissions-intensive technologies, infrastructures, and business practices (Kivimaa & Kern, 2016; Markard et al., 2020). Relevant targets for such interventions include gasoline engines, fossil-fuel power plants, heating systems and gas networks (Meckling & Nahm, 2019; Trencher et al., 2022).

(S4) Economic Case for Climate Mitigation and Fiscal Measures: The net zero socio-technical transition has considerable economic and employment implications. A difficult balancing act, it requires alignment of climate-mitigation measures with other strategies designed to ensure livability and a vibrant, competitive, and equitable economy, including consideration of the United Nations Sustainable Development Goals (Dhakal & Ruth, 2017; Ramaswami et al., 2021). Tensions between climate action and other societal goals may be alleviated when decarbonization is posited as an economic or social development strategy (Griffith et al., 2020a; Phadke et al., 2020). Since the capacity for cities to catalyze accelerated and transformative change tends to correlate with the availability of economic and human resources (Wolfram, 2016), the case for climate mitigation can be strengthened by linking CAP ambitions to local economic and job-creation policies (Gouldson et al., 2012; 2018). Cities' annual climate budgets have become an important instrument designed to direct CAP implementation and monitoring, as well as enhancing coordination of local climate governance by clarifying commitments, expectations, and responsibilities (Barnhusen, 2019; Vedeld et al., 2021).

Table 1: Framework for Assessing Potential for Accelerated Systemic Decarbonization

Strategy	Indicator	Does the CAP…?	Key Supporting literature
(S1) Approach to Target-Setting	(1) Detailed Emission Reduction Measures (ERMs)	Include clear and detailed descriptions of ERMs broken down by sector, with an explicit baseline (preferably 1990) and interim targets?	Bailey, 2017; Sethi et al., 2020
	(2) Transparent Assumptions and Data	Clearly explain emission-data-collection methodologies and include easy access to annual GHG inventories?	Carloni & Green, 2017; Kennedy et al., 2010; Wei et al., 2021
	(3) Inclusion of Scope 3 Emissions	Target direct emissions occurring in the municipality (scope 1) and emissions from grid supplied energy to the municipality (scope 2) as well as in-direct, consumption-related, and out-of-boundary emissions (scope 3)?	Chavez & Ramaswami, 2011; Chen et al., 2019; Dahal & Niemelä, 2017; Ramaswami et al., 2021; Tong & Ramaswami, 2022
(S2) Political Enabling Environment	(4) Climate Emergency Declaration	Include declaration of a climate emergency?	Davidson et al., 2020; Dyson et al., 2022; Greenfield et al., 2022; Gudde et al., 2021; Ruiz-Campillo et al., 2021
	(5) Participatory Governance Innovations	Utilize a range of civic engagement activities to ensure that CAP development and implementation is inclusive and incorporates ideas of the public? Traditional methods include public commenting and seminars while novel methods include citizen juries, assemblies, and participatory budgeting.	Cabannes, 2021; Gherghina & Tap, 2021; King & Wilson, 2022; Li & Lin, 2022; Sandover et al., 2021; Wells, 2022; Wells et al., 2021
(S3) Comprehensive Implementation Measures	(6) Land Use and Spatial Planning	Seek alignment between CAP decarbonization goals and spatial planning to attain synergies or avoid tradeoffs.	Capellán-Pérez et al., 2017; Kyriakopoulos, 2023; Li & Lin, 2022; Ravetz et al., 2021
	(7) Heterogeneity of Technology Interventions	Include measures to accelerate diffusion of multiple and diverse technologies in different sectors (e.g., net zero buildings, electric mobility, waste to energy, renewable electricity)?	Kobashi, 2020; Lamb et al., 2019; Sethi et al., 2020

	(8) Cross-Cutting/Cross Boundary	Include cross-cutting and/or cross-boundary measures that span multiple sectors, geographical scales, or jurisdictions to address transboundary emission sources (e.g., from power generation, waste management and water supply)?	Chavez & Ramaswami, 2011; Hoppe et al., 2016; Li & Lin, 2022; Papachristos et al., 2013; Tong & Ramaswami, 2022
	(9) Systemic Innovation	Include policies and measures that tackle multiple points within systems/sectors (e.g., linking EV charging infrastructure with zero-carbon electricity) or between sub-systems (e.g., energy production and energy consumption, transportation, and electricity supply, etc.)?	Geels et al., 2017; Hodson & Marvin, 2010; Jacobsson & Bergek, 2011; Markard et al., 2020; Mattes et al., 2015; Roberts & Geels, 2019; Rosenbloom et al., 2020
	(10) Supply and Demand Interventions	Include measures to address both supply and demand (e.g., promoting growth in renewable electricity supply while controlling/reducing overall electricity demand or expanding the supply of sustainable public transport while discouraging use of private vehicles)?	Axsen et al., 2020; Sethi et al., 2020; Yang et al., 2021
	(11) Lifestyles and Consumer Behavior Measures	Include goals or measures to reduce consumption-related emissions by tackling lifestyles and behavior?	Bailey, 2017; Lunetto et al., 2022; Markard et al., 2020; Stankuniene et al., 2020
	(12) Phase-out of Emissions-Intensive Technologies	Include goals or measures to accelerate the phase-out of emissions-intensive technologies and configurations (e.g., gasoline vehicles, oil/gas heating systems)?	Green, 2018; Kivimaa & Kern, 2016; Markard et al., 2020; Meckling & Nahm, 2019; Trencher et al., 2022; Yang et al., 2021
(S4) Economic Case and Fiscal Measures	(13) Consideration of Economic Factors	Consider or plan for economic factors related to decarbonization measures, for instance, by estimating benefits such as new local investments, financial expenditure savings, employment generation and business creation.	Gouldson et al, 2014; 2018; Griffith et al., 2020a; Phadke et al., 2020
	(14) Alignment of Municipal Expenditure and Climate Action	Include: (1) a formally adopted climate budget, and (2) financial indicators to monitor progress towards climate goals implementation?	Barnhusen, 2019; Echeverri, 2018; Vedeld et al., 2021

4.3 Case Study Selection

The six case-study cities selected for analysis are all sub-national jurisdictions. These are Copenhagen (Denmark), Leeds (United Kingdom), Oslo (Norway), San Francisco (United States), Australian Capital Territory (ACT) (Australia) and Kyoto City (Japan)—listed in order of target years for reaching net zero, from earliest to latest. Each case study was selected because it:

- features among its country's frontrunner cities in terms of climate-policy ambition. For instance, San Francisco is an active leader in the C40 Climate Leadership network, while Kyoto is known as an environmentally progressive city in Japan and gave its name to the 1997 Kyoto Protocol. Copenhagen is recognized as a green economy and renewable-energy leader in Europe, especially after hosting the United Nations climate conference (COP 15) in 2009.
- exemplifies one point on a spectrum of ambition and decarbonization speed, which can be gauged from the target year for achieving net zero. The sample includes a range of decarbonization schedules that reflect accelerated ambitions (Copenhagen, 2025; Leeds, 2030; Oslo, 2035; San Francisco, 2040; Australian Capital Territory, 2045) or are more conservatively aligned with national or international targets (Kyoto, 2050). More specifically, in this sample selection, each city's net zero goal is separated by five years. This reflects the expectation that different decarbonization schedules would involve different sets of climate strategies.
- represents contrasting practices in industrialized economies of the global north. While these case studies fail to capture decarbonization efforts in the global south (Delina, 2016; Lamb et al., 2019; Wei et al., 2021), they nonetheless provide an important opportunity to assess the potential for accelerated systemic decarbonization in well-resourced governments (in terms of finance, technology, expertise, etc.) located in countries that have contributed substantially to historical global emissions. Practices in these cities are expected to prove instructive for less ambitious or still developing cities.

4.4 Data Sources

The respective CAP documents examined are listed in **Table 2**. The selection of documentation for review assures that this body of evidence includes: (1) the most recent CAP as well as any preceding ones; (2) CAP monitoring reports where available; (3) local annual GHG inventories where available; and (4) other related policy documents when referred to in the CAP (e.g., municipality financial plans and other policies most relevant to climate mitigation). Since the analysis and argumentation presented here are confined to CAPs and such documentation, some cities may have implemented particular strategies even though these are not mentioned in the examined documents. Thus, while recognizing that urban climate governance encompasses a wide spectrum of environmental management tools as well as involving national and international laws, limiting the scope of evidence for review to CAPs and related documents facilitates the identification of a "common ground" of policies and measures for the case study cities.

All documents were screened for evidence of the strategies and indicators compiled in the framework described above (**Table 1**). When applying the framework, a simple binary scoring system was applied to comparatively assess the extent to which each city's CAP reflects each indicator. Specifically, this approach draws on approaches elsewhere (Trencher et al., 2021) by assigning two values, indicating when there is "*strong evidence of multiple measures that satisfy the indicator*" as opposed to "*weak evidence or limited measures that satisfy the indicator*." All scoring decisions and evidence were cross-checked by three authors to increase the internal validity of the data, reduce subjective interpretation, and identify inconsistencies. Cognizant that other studies have adopted finer-grained scoring schemes when evaluating policies and innovation strategies (Schaffrin et al., 2015), a simple binary system was deemed as an effective means of dealing with the volume and heterogeneity of qualitative evidence examined. This decision overcomes the difficulty of creating an objective and replicable scheme with a higher number of scoring variables.

All data and scoring decisions for this step are compiled in the **Supplementary Material**.

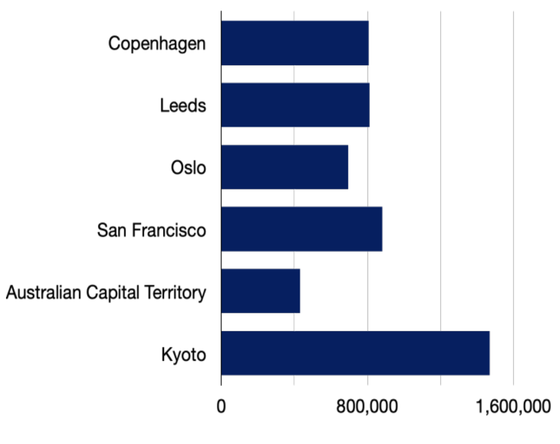
Table 2: CAP Documents Reviewed

City	Documents and Codes
Copenhagen	CPH1: Roadmap 2021-2025 CPH2: Roadmap 2017-2020 CPH3: CPH 2025 Climate Plan CPH4: CO_2 Accounts for 2020 (DK) CPH5: Roadmap 2021-2025 (DK) CPH6: Copenhagen's Municipal Plan 2019 CPH7: Circular Copenhagen: Resource and Waste Management Plan 2024 CPH8: Copenhagen Climate Action Plan 2009 CPH9: Draft Plan for CO_2 Reduction in Copenhagen 1990-2010 CPH10: Annex 2: Climate Budget – Climate Impact of Selected Budget Initiatives in the 2023 Budget (DK)
Leeds	LDS1: A Net Zero Carbon Roadmap for Leeds LDS2: Science Based Carbon Budget, Carbon Targets and Carbon Roadmap for Leeds LDS3: Leeds Climate Change Strategy – Making the Change 2012 to 2015 LDS4: Assessing and Building City-Level Readiness for Climate Action LDS5: The Leeds Local Plan Update Scoping and Consultation 2021 LDS6: The Leeds Climate Change Citizens' Jury, September – November 2019
Oslo	OS1: Appendix to Oslo's Climate Budget 2023 OS2: 2020 Climate Strategy for Oslo (towards 2030) OS3: 2016 Climate and Energy Strategy for Oslo OS4: Appendix to Oslo's Climate Budget 2022
San Francisco	SF1: Climate Action Plan 2021 SF2: Focus 2030: A Pathway to Net Zero Emissions 2019 SF3: Climate Action Strategy 2013 Update SF4: 2019 San Francisco Sector-Based Greenhouse Gas Inventory at a Glance SF5: Proposed Electric Vehicle Roadmap for San Francisco, 2019
Australian Capital Territory	ACT1: ACT Greenhouse Inventory for 2021-2022 ACT2: Sustainable Energy Policy 2020-25: Discussion Paper ACT3: Climate Strategy 2019-25 ACT4: 2021-22 Ministers Annual Report under the Climate Change and Greenhouse Gas Reduction Act 2010 ACT5: A new climate change strategy and action plan for the Australian Capital Territory, 2012 ACT6: Climate mitigation and adaptation in the ACT: Costs, benefits, and implications ACT7: Building Canberra's Circular Economy – Draft ACT Circular Economy 2022-2025
Kyoto City	KYO1: Program of Global Warming Counter Measures 2021-2030 (JP) KYO2: Program of Global Warming Counter Measures 2011-2020 KYO3: Program of Global Warming Counter Measures 2006 (JP) KYO4: Kyoto City's Global Warming Countermeasures 2021 (JP)

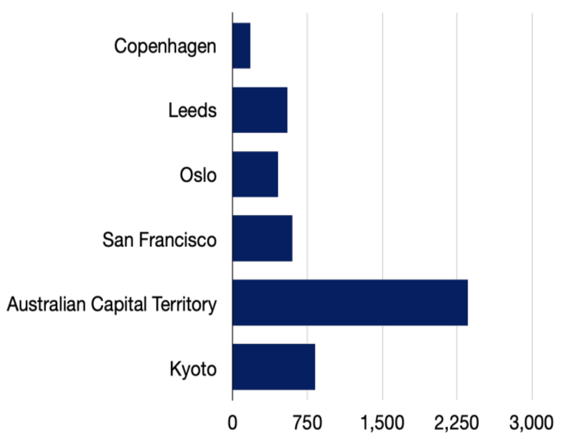
Section 5. Introduction to the case studies

5.1 Key Characteristics

Figure 2 compares each city's population, land area, density, total CO_2 emissions and per capita emissions. Kyoto has the largest population (although growth has stagnated in recent years) and CO_2 emissions. ACT has the biggest land area and is the only state-level government. Copenhagen has the highest population density per square kilometer. San Francisco and Leeds have the highest CO_2 emissions per capita. The breakdown between surface transport and other emission sources in each locality is also presented since the CAP review revealed that these are currently the most difficult to mitigate, often representing over 40% of local emissions. Kyoto, having the least surface-transport emissions by far, is the exception. Not only does this city have a dense center and limited sprawl, but it also has an extensive public transport network and has pursued a walkable and cyclable townscape for well over a decade.



Population



Land Area (km^2)

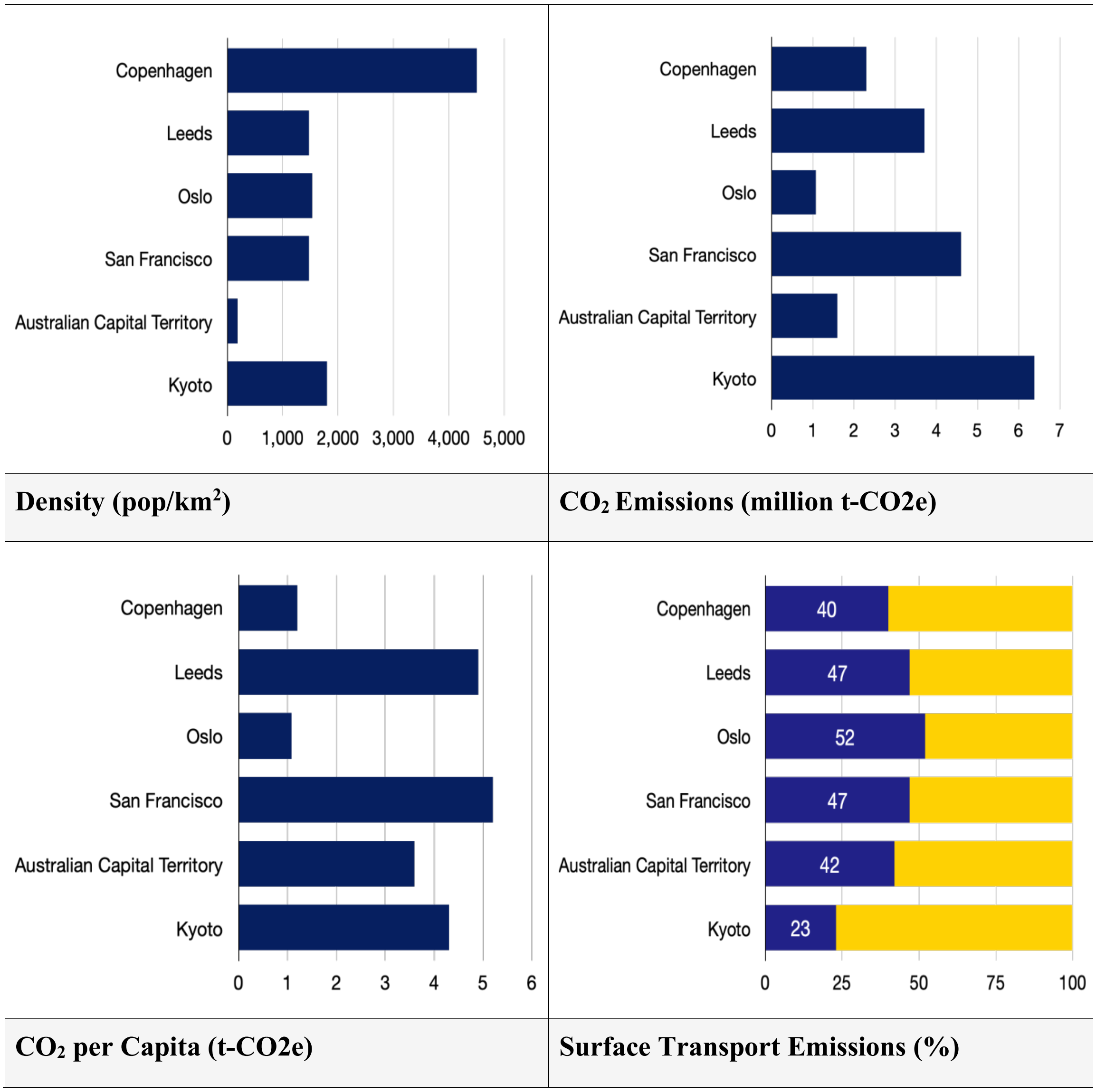


Figure 2: Characteristics of Case Study Cities

Data source: Documents from each city, including CAPs and GHG accounts (see Table 2).

5.2 Emissions Reduction Pathways

To deepen understanding of the decarbonization context of each CAP, stylized emission reduction pathways are presented for each city (**Figure 3**). Historical emissions were derived from CAP documents and related GHG inventory reports. Future decarbonization pathways are based on projected emissions presented in CAPs and supporting documentation. With baselines set to 1990, the figures visualize the degree of acceleration or the steepness of the emissions decline curve that each city must follow to achieve net zero by the target year. These pathways are categorized as linear, delayed, or accelerated, following UNEP (2021):

- **Linear:** emission reductions trace a direct line from the 1990 base year to net zero target year.
- **Delayed:** emissions initially increase from the base year, and/or reductions progress more slowly than the linear pathway, resulting in higher cumulative emissions.
- **Accelerated:** emission reductions are deeper than the linear path and aim to reach net zero before 2050. As well as reducing emissions more quickly, this results in fewer cumulative emissions than the two other pathways.

Copenhagen exemplifies an accelerated emission reduction pathway. Copenhagen set an ambitious target to reach net zero by 2025, aiming to be the first carbon-neutral city in the world (Damsø et al., 2017). The city also aims to achieve 100% renewable electricity by the same year. Copenhagen's emissions reduction trend has accelerated over the past 13 years, with emissions dropping by around 45% between 2005 and 2018 (attributable mainly to progress in decarbonizing the energy sector via increased share of renewables in combined heat and power production). Reaching net zero by 2025 would require future emissions to decline by 6.4% per year. However, the city's own projection for the future emissions reduction trajectory, presented in CPH1, implies that attainment of the net zero 2025 target will be delayed, mainly because of stubbornly persistent emissions from road traffic and buildings. Tackling these residual emissions has thus become the core task for the successive CAPs covering 2025 onwards [CPH3]. This could require offsets through renewable-energy projects and nature-based solutions [CPH1].

Leeds, another ambitious case, aims to reach net zero by 2030. Its historical decarbonization pathway was initially linear but accelerated from 2010 onwards. Since city-level emissions data has only been available online from 2005 onwards, past emission trends for Leeds from 1990 were obtained from Gouldson et al. (2012), who applied a backcasting methodology using national datasets for emissions and energy. Maintaining the accelerated emission reduction pathway needed to hit net zero by 2030 requires that future emissions for the city decline by 3% per year.

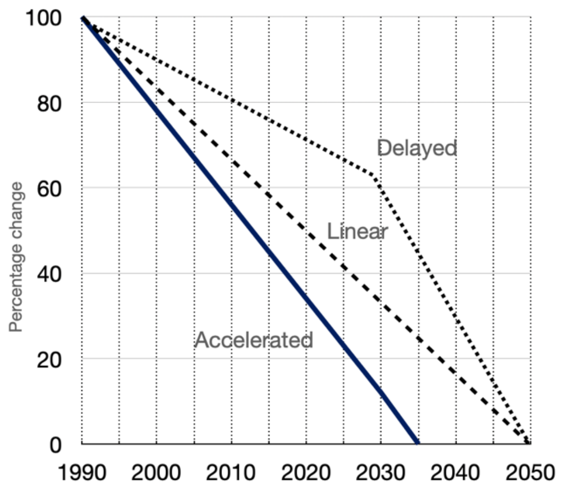
Oslo aims for net zero by 2035. Its historical decarbonization pathway was delayed, exhibiting a climbing trend between 1990 and 2013. Thereafter, emissions began to decline, entering a pronounced acceleration stage after 2015. Oslo's updated CAP in 2020 [OS2] aims to reduce direct emissions by 95% by 2030 (compared to 2009), potentially reaching net zero by 2035. To reach this target, however, Oslo will require direct engagement from the central government and the local business community. New ERMs proposed in 2022 [OS1] to accelerate decarbonization include extending zero-emission vehicle zones within the city and increasing road tolls for internal combustion engines. It is projected that future emissions for Oslo would need to decline by 2.4% per year to meet the net zero 2035 target.

Aiming to reach net zero by 2040, San Francisco's historical decarbonization pathway was modestly delayed between 1990 and 2020. This reflects ongoing challenges in pursuing decarbonization as population and economic activity grow rapidly. The most recent CAP [SF1] fast-tracked the net zero target from 2050 to 2040, triggering the need for accelerated actions. This would effectively involve a 90% reduction in sector-based emissions by 2040 and offsetting the remaining 10% residual emissions through tree-planting and soil sequestration. It is projected that San Francisco's future emissions need to decline by 3.1% per year to reach the net zero target by 2040.

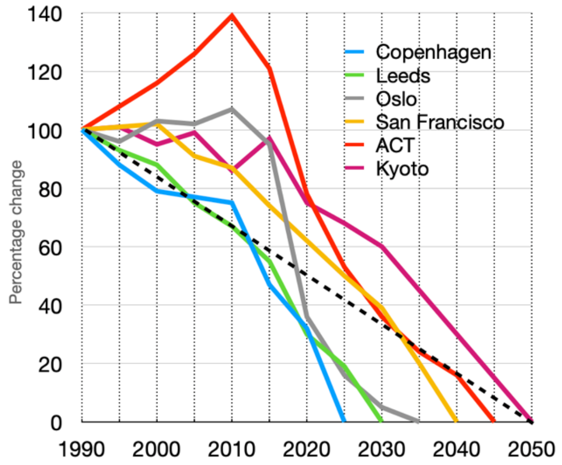
The Australian Capital Territory aims, less ambitiously, to hit net zero by 2045. The historical decarbonization pathway has also been significantly delayed, with emissions growing between 1990 and 2010 (during which time the population also grew from 279,000 to 432,000). This picture was dramatically transformed in 2019 after ACT attained 100% of its electricity from renewables produced through contracts with wind farms and large-scale solar farms, many outside territorial boundaries. Largely because of this structural change, emissions in 2022 dropped by 47% compared to 1990 levels [ACT1]. Based on performance from 1990 to 2019, ACT's challenge going forward will be how to maintain an accelerated decarbonization trend to ensure that future emissions decline at the needed rate of 3% per year.

The more conservative case of Kyoto—aiming to reach net zero emissions by 2050—shows that both historical and projected emission reduction pathways are delayed. Between 1990 and 2019, historical emissions in the city declined marginally, with much progress lost following the Fukushima nuclear accident in 2011 and the associated increase in the share of electricity generation from fossil fuels at the national level (Kharecha & Sato, 2019). Nevertheless, influenced by its proud history of progressive climate action, in May 2019 Kyoto declared a commitment to reach net zero by 2050. This was two years before the national administration's similar commitment. Kyoto's future emissions will need to decline by 2.5% per year to reach the net zero target by 2050.

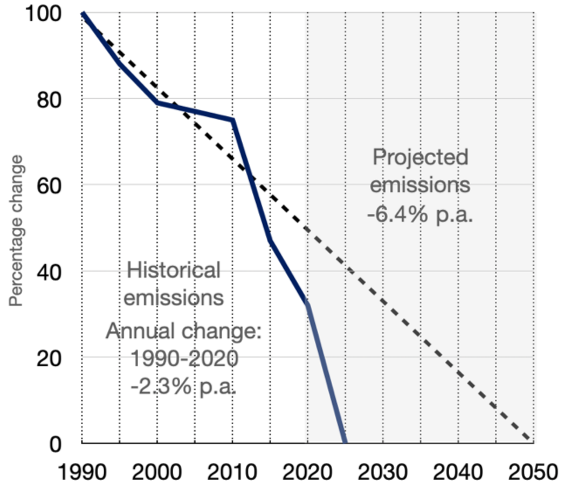
Figure 3 shows that to reach the pledged net zero targets, all six cities must accelerate their rate of decarbonization compared to historical emission trends. The next section assesses their potential to achieve this objective.



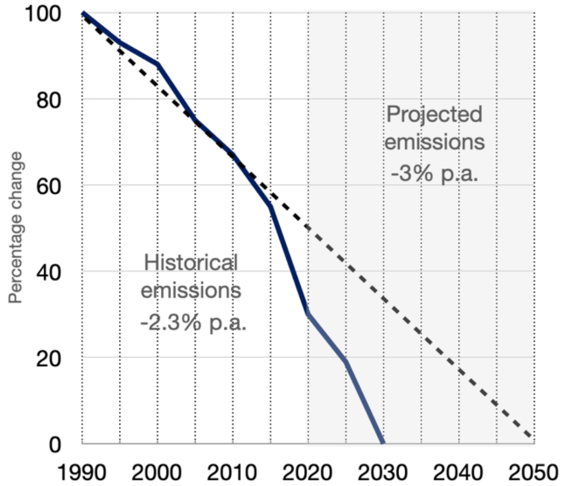
Decarbonization Pathways (1990 = 100)



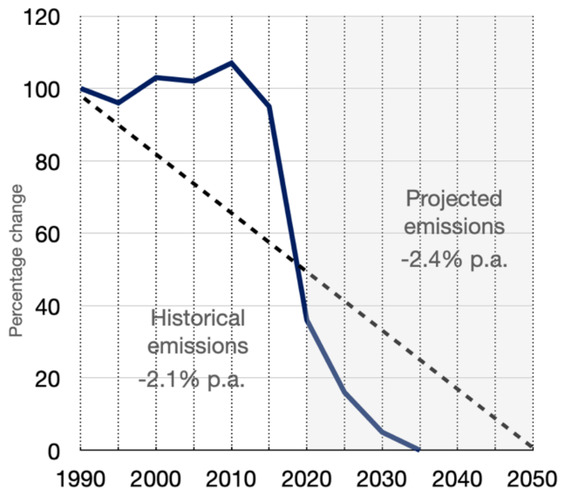
All Pathways



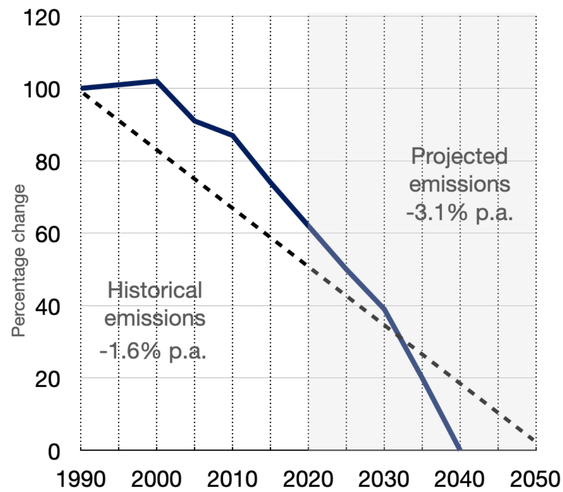
Copenhagen



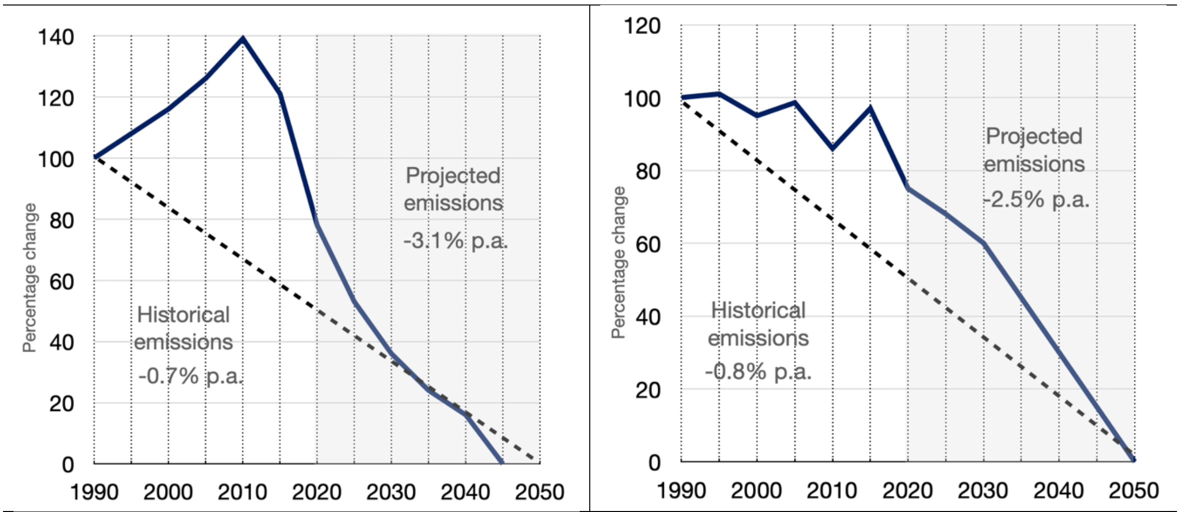
Leeds



Oslo



San Francisco



Australian Capital Territory	**Kyoto City**

Figure 3: Emission Reduction Pathways (Historical and Projected) Towards Net Zero Target

Note. Main references used to create historical pathways and forecast future decarbonization speed are as follows. Copenhagen: Figures presented in CPH1 (p12) and CPH5 (p7). Leeds: Figure 13 in LDS1 (p43). Oslo: Section 3 in OS1 (p6) and Figure 3 in OS4 (p19). San Francisco: Figure 6 in SF1 (p39). ACT: Figure 1 in ACT3 (p4). Kyoto: see item 13 in KYO1 (p13). All references appear in Table 2.

Section 6. Results

To assess the potential of each city to achieve accelerated systemic decarbonization, the contents of each CAP were examined and scored in terms of the extent to which they reflect the four generic strategies (S1 to S4) and fourteen indicators (S1-1 to S4-14) from the framework (**Table 1**). Scoring results are presented in **Table 3**. All data and scoring decisions underpinning this analysis are summarized in **Supplementary Material**.

Table 3: Assessment of the Potential for Accelerated Systemic Decarbonization

Strategy	Indicator	C	L	O	SF	ACT	K
(S1) Approach to Target-Setting	(1) Detailed Emission Reduction Measures (ERMs)	●	●	●	●	●	●
	(2) Transparent Assumptions and Data	●	●	●	●	●	●
	(3) Inclusion of Scope 3 Emissions	○	○	○	●	○	○
(S2) Political Enabling Environment	(4) Climate Emergency Declaration	○	●	○	●	●	●
	(5) Participatory Governance Innovations	○	●	○	●	●	○
(S3) Comprehensive Implementation Measures	(6) Land Use and Spatial Planning	●	●	●	●	●	○
	(7) Heterogeneity of Technological Interventions	●	●	●	●	●	●
	(8) Cross-Cutting/Cross Boundary	●	○	●	●	●	●
	(9) Systemic Innovation	●	○	●	●	●	●
	(10) Supply and Demand Interventions	●	●	●	●	●	●
	(11) Lifestyles and Consumer Behavior Measures	○	○	●	●	●	●
	(12) Phase-out of Emissions-Intensive Technologies	●	○	●	●	●	○
(S4) Economic Case and Fiscal Measures	(13) Consideration of Economic Factors	●	●	○	●	○	○
	(14) Alignment of Municipal Expenditure and Climate Action	●	○	●	○	○	○

Notes: C=Copenhagen, L=Leeds, O=Oslo, SF=San Francisco, ACT=Australian Capital Territory, K=Kyoto City. Solid circles ● indicate strong evidence of multiple measures that satisfy the indicator, while empty circles ○ indicate weak evidence or limited measures that satisfy the indicator.

6.1 Overall Observations

Although the analysis does not assume that all indicators are equally important or that a higher number satisfied would correlate directly with a higher potential to reduce emissions, the analysis shows that two cities (San Francisco, and ACT to a lesser extent) stand out as having satisfied most indicators. Next, Copenhagen and Oslo perform almost identically against many indicators. Conversely, Leeds and Kyoto have satisfied the fewest indicators across the sample. This result for Leeds is surprising since the city has adopted an ambitious goal to reach net zero by 2030 and has declared a climate emergency.

In terms of widely satisfied indicators, all CAPs contained clear and detailed descriptions of both ERMs, broken down by sector (S1-1) and baselines, which are set to 1990. Similarly, all cities explicitly disclose the methodologies and assumptions used, and make the datasets of GHG emission inventories publicly available (S1-2). All cities' climate strategies feature a wide heterogeneity of interventions to confront various emission sources (S3-7), including supply-side and demand-side (S3-10). Five of the six cities outline the intention to use land use and spatial planning policies to pursue decarbonization objectives (S3-6), implementing or discussing strategies to tackle emission sources outside city boundaries (S3-8). Of high interest, widespread evidence of systemic efforts to spur innovation (S3-9) was found, with five cities tackling important sources of emissions at multiple points within or across systems and sectors.

Other indicators were met by a smaller majority of four cities: climate emergency declarations (S2-4) and measures to tackle emissions originating from consumer lifestyles and behavior (S3-11). CAPs in these cities discuss a surprising diversity of strategies, including promoting the adoption of energy-efficient or gas-free electrical appliances (Kyoto, ACT), promoting sustainable mobility (ACT), and reducing household or commercial waste generation. Notably, some cities such as San

Francisco and Oslo explore the potential for more ambitious proposals to tackle lifestyle-based emissions, pledging to promote plant-rich diets and reduce food waste [OS2, SF1]. Four cities seek to complement their innovation-focused efforts with measures to phase out emissions-intensive technologies. These include initiatives to phase out the installation of gas infrastructure and appliances in new buildings (ACT, San Francisco), gasoline engines in private and public vehicles (ACT, Copenhagen, San Francisco, Oslo) and fossil-fuel heating (Copenhagen, Oslo).

The analysis unearthed four areas where engagement with strategies exhibiting high climate mitigation potential is comparatively weak. First, only one city (San Francisco) has set explicit targets to tackle scope 3 or consumption-based and out-of-boundary emissions (S1-3). It aims to reduce these emissions by 80% by 2050 compared to the 1990 baseline [SF1], even establishing a consumption-based GHG emissions inventory. CAPs in the other five cities focus on scope 1 and 2 emissions. One of these excludes all mention of scope 3 emissions (Kyoto), while four set scope 3 mitigation actions as a future ambition (ACT, Leeds, Copenhagen, Oslo).

Second, participatory governance innovations (S2-5) were observed in only half of the sample. Three cities (Leeds, San Francisco, ACT) have experimented with measures such as climate commissions and the integration of public comments when carrying out CAP amendments. In the case of Leeds, holding a citizens' jury resulted in recommendations that, if implemented, would significantly increase the pace of future emission reduction for the city. Meanwhile, San Francisco reached out to over 238,000 people via online workshops and open-house events. Its CAP shows an impressive degree of attention to comments received, outlining meticulously how these affected CAP development [SF1]. This development process in the San Francisco case included a racial and social equity assessment to ensure that the climate mitigation actions' benefits or negative outcomes are not unevenly distributed across racial or societal segments. This said, contrary to expectations, strong evidence was not found in any city of other novel forms of public engagement, such as citizen assemblies or participatory budgeting.

Third, only three cases (Copenhagen, Leeds, and San Francisco) included formal analysis of the benefits or costs of various climate mitigation actions. The benefits articulated by quantitative appraisals in these cities include job creation, reduced energy expenditures and avoided deaths from air pollution.

Fourth, only two cities (Copenhagen and Oslo) have adopted an annual climate budget with financial indicators to monitor CAP implementation and performance [OS1], along with estimates of emission reductions associated with relevant budget initiatives [CPH10]. CAPs in the other cities do not explicitly communicate funding arrangements for the various climate-mitigation actions envisioned. It is thus unclear if CAP implementation would depend on existing municipal budgets or new funding mechanisms, including external sources.

6.2 Case-Level Evidence

The following sections summarize key observations regarding the presence and absence of strategies and indicators for each city examined.

6.2.1 Copenhagen

Pursuing climate neutrality by 2025, Copenhagen's CAP satisfies ten indicators. It outlines a comprehensive array of ERMs in four-year implementation roadmaps [CPH1 and CPH2]. The ERMs are organized around four pillars identified in CPH3: energy consumption, energy production, mobility, and municipal operations. This is supported by comprehensive implementation measures (S3), including the phase-out of technologies such as biomass heating (to be replaced by geothermal energy and heat pumps) and fossil-fuel vehicles. The city also aims to become fossil-fuel-free by

2025. An interesting feature of Copenhagen's approach is the resolve to tackle out-of-boundary emissions sources in Greater Copenhagen. The CAP states that the promotion of cohesive measures is more important than administrative boundaries [CPH6] and encompasses measures such as purchasing farmland outside the city to increase semi-urban woodland [CPH1]. Another noteworthy approach is the preparation of Copenhagen's first climate budget in 2023. This includes estimates of potential emission reductions associated with selected ERMs and provides a basis for negotiating the city's general budget [CPH10].

Like most cities, Copenhagen's CAP shows limited consideration of consumption-based and transboundary emissions (scope 3). Another area of weak evidence or limited measures is the political enabling environment (S2). For instance, Copenhagen has not declared a climate emergency, and its CAP and connected documents provide no evidence of explicit community engagement via participatory governance innovations.

6.2.2 Leeds

Leeds CAP meets eight indicators. Notably, it satisfies both indicators for the political enabling environment (S2). After declaring a climate emergency in 2019, the city fast-tracked the net zero target year from 2050 to 2030. Several participatory governance innovations were found, including the Leeds Climate Commission (established in 2017 as a multi-stakeholder partnership) and the Leeds Climate Citizens' Jury (University of Leeds, 2019; Wells et al., 2021). The Leeds Climate Commission prepared two climate roadmaps in 2019 [LDS2] and 2021 [LDS1]. This led to the identification of multiple ERMs, grouped into three categories: cost-effective options, ambitious options (including proposals from the Leeds Climate Citizens' Jury) and stretch options. The latter include difficult-to-implement ERMs, such as zero-emissions drivetrains in heavy-duty transport. Not all citizen requests materialize, however. One source of contention is the expansion of the local airport. The Citizens' Jury recommended cancelling this plan since it would increase transport-related emissions. Leeds also exhibits explicit measures to integrate land use and spatial planning (S3-7): the CAP requires consideration of impacts from land use on climate-change adaptation and mitigation goals [LDS5]. Furthermore, Leeds makes a strong economic case for decarbonization, leveraging research by the University of Leeds to highlight the potential returns on ERM investments. This study (Gouldson et al., 2017) found that many measures offer fast payback periods and would generate substantial new employment.

Despite ambitions to reach net zero by 2030, six indicators were not met. Efforts to tackle scope 3 emissions (S1-3) are absent and deferred to future CAPs [LDS1]. For cross-cutting/cross-boundary opportunities, systemic innovations and phasing out unsustainable technologies, explicit measures are also lacking. With respect to systemic innovation (S3-9), although the CAP [LDS1] presents ERMs by sector (homes, public and commercial buildings, transport, and industry), it does not promote innovation within systems or sectors or between sub-systems. For instance, only four transport ERMs are introduced (cycle highways, more electric buses, increased public transport ridership, and more electric cars) while details are lacking on how the wider transport system across the city would be transformed. Meanwhile, although the CAP affirms the importance of behavioral actions like reducing meat consumption and food waste [LDS2], implementing of concrete measures is left for future CAPs [LDS1]. Finally, the city lacks a dedicated climate budget and does not outline measures to secure municipal expenditure in support of climate goals (S4).

6.2.3 Oslo

Oslo's CAP shows strong evidence of multiple measures for ten indicators. ERMs are presented under 16 priority areas related to land use, transport, building and construction, waste, and energy [OS2]. The CAP includes comprehensive implementation measures (S3) to pursue these, satisfying all indicators. For example, Oslo aims to become fossil-fuel-free by 2030 and leverages several phase-out interventions. Targets include oil-fired heating (district and individual buildings) and gasoline engines in private and public transport. A pioneering feature of Oslo's actions is the establishment of an annual climate budget, implemented since 2017 [OS1]. This increases the transparency of municipal expenditure on ERMs and highlights progress made towards attaining climate targets (Barnhusen, 2019; Vedeld et al., 2021).

Four indicators have limited or missing measures. First, though pledging to tackle scope 3 emissions (S2-3) by 2030, the CAP lacks details of concrete implementation measures [OS2]. Second, like Copenhagen, Oslo has not declared a climate emergency (S2-4). Third, although there has been extensive public and business engagement in CAP formulation, evidence of innovations like citizen assemblies were not identified (S2-5). Finally, the CAP does not articulate a strong economic case for pursuing climate mitigation (S4-14). Its discussion of economic benefits and job creation opportunities is limited and does not formally estimate this potential.

6.2.4 San Francisco

San Francisco's climate actions are the most indicative of accelerated systemic decarbonization, meeting all indicators except one. Not only does the city pursue decarbonization in wide areas spanning energy, buildings, transport, waste, green spaces, agriculture, and lifestyles, but most importantly, it explicitly aims to reduce scope 3 emissions in addition to scope 1 and 2 (S1-3). It is the only city using both consumption and sector-based emission inventories. Because reducing scope 3 emissions requires ambitious decarbonization strategies, one notable consequence is that San Francisco's adoption of consumption-based emission inventories has necessitated measures to influence consumer behavior (S3-11).

San Francisco has also used a climate emergency (S2-4), declared in 2019, to call for accelerated decarbonization and for sliding the CAP net zero target forward by ten years, from 2050 to 2040. Its climate action planning process involved extensive community engagement (S2-5). These activities support the pursuit of systemic acceleration and wider CAP ownership by encouraging the community to "identify new actions and integrate their priorities, data, and best practices into the plan" [SF1, 16]. Furthermore, by assessing the impact of decarbonization actions on different racial and societal segments, San Francisco's CAP provides a pioneering model of how to incorporate equity and justice considerations in climate planning. It is one of only three cases that formally examines the economic consequences of pursuing a transition to net zero (S4-13). This analysis [SF1] includes a detailed breakdown of the consequences of various actions in terms of financial cost, pollution mitigation, social costs (e.g., reduced morbidity from air pollution) and financial savings from reduced energy expenditures. San Francisco has also articulated strong ambitions to phase out emissions-intensive technologies (S3-12). In addition to gasoline-based transport, these actively target natural gas use in buildings. As a step towards mandating all-electric building systems, new gas installations have been banned since 2021.

The sole indicator not satisfied concerns funding mechanisms (S4-14): the city has not prepared an explicit climate budget. The CAP does not explain the procedures for linking municipal expenditure patterns to ERM implementation.

6.2.5 Australian Capital Territory (ACT)

ACT's CAP satisfied eleven criteria, the second highest in the sample. ACT provides another example where a climate emergency (S2-4) has accelerated a city's decarbonization ambitions: declared in May 2019, this catalyzed a shift of the net zero target year from 2050 to 2045. ACT has also engaged extensively with the public in developing its CAP (S2-4). A flagship instrument was the Climate Change Council, an independent advisory group composed of academics and representatives from business and civil society. The scope of ERMs described in the CAP is comprehensive (S3-7), targeting transportation, energy, buildings, urban development, waste management and biodiversity. Efforts in transport exemplify a systemic approach (S3-9), aiming to effect system-wide change through integrated actions such as: providing sustainable public transport (electric light-rail and buses); planning for a compact city and car-free zones to reduce car use; promoting cycling, car-sharing schemes, and ZEV adoption; and establishing electric charging infrastructure. The ACT provides another example of conscious measures to align land use and spatial planning with decarbonization goals (S3-6). Notably, its CAP seeks alignment with key policies like the 2018 Planning Strategy, the Sustainable Energy Strategy, and the Canberra Living Infrastructure Plan. One outcome of this alignment is the commitment to achieve compact city planning by concentrating new housing developments in existing urban areas and along public transport routes [ACT3].

In terms of missed opportunities, while the CAP superficially considers the costs and benefits of climate mitigation, it does not formulate a clear economic case for climate mitigation, nor does it conduct a formal analysis (S4-13). ACT's CAP does not provide information about the financial resources available to support implementation (S4-14) or on how expenditure and budgetary patterns will change (or have changed).

6.2.6 Kyoto

Kyoto's CAP satisfies eight indicators, the lowest number in the sample. This possibly reflects its lower ambition in terms of decarbonization speed, which aims for net zero by 2050. Nevertheless, its CAP outlines several strategies expected to spur decarbonization. For example, it details its GHG emissions accounting methodology (S1-2), actively maintains emission inventories and publishes an annual report on emission trends and ERM implementation progress. Moreover, the city declared a climate emergency in December 2020 (S2-4). Notably, the description of ERMs reflects a bias towards technological solutions, for instance by anticipating the spread of electric and fuel-cell vehicles along with innovations in energy supply and demand management. This technocentric focus is apparent in efforts to tackle demand-side emissions (S3-10) and promote climate-friendly lifestyles (S3-11). For instance, emission reductions are envisaged around diffusing energy-efficient electric appliances and housing.

Kyoto's CAP has missed out on six indicators expected to boost prospects for rapid and systemic decarbonization. First, it does not currently address scope 3 emissions (S2-3), nor does it mention ambitions to do so in the future. Second, the CAP provides limited evidence of public engagement (S2-5). Following a standard procedure for environmental policy development in Japan, consultations during the CAP's formulation were limited to public comments and an expert committee drawn from academia, non-governmental bodies, and the business sector. Third, links between the CAP and land use plans (S3-6) are unclear, though the Kyoto Urban Plan is mentioned as a "connected" document. Fourth, with respect to phasing out carbon-intensive technologies (S4-12), the city has taken an explicit stance against coal-fired power, being part of the Powering Past Coal Alliance. However, the CAP fails to outline concrete actions to catalyze the phase-out of specific technologies. For example, while the CAP envisions achieving fossil-fuel-free public transport by 2050, it does not outline measures to curb the use of gasoline engines besides efforts to promote the adoption of zero-emission vehicles. Fifth, the CAP lacks any discussion or formal analysis of the economic case for climate action (S4-14), and sixth, the city has not established a dedicated climate budget (S4-15).

Section 7. Discussion

The above analysis reveals considerable variation in CAP development and implementation across the cases. San Francisco, satisfying most indicators in the framework, corresponds most closely to the conception of systemic accelerated decarbonization. Not only is San Francisco the only city currently addressing scope 3 emissions, but additionally its CAP represents a key step forward in placing people at the center of climate action planning, including considering of racial and social equity [SF1]. In contrast, the other case study cities have not addressed several strategies expected to lead to accelerated systemic decarbonization. These deficiencies may compromise their efforts to achieve more rapid and transformative outcomes.

The first major cause for concern relates to the lack of consideration of scope 3 emissions. Originating largely from the consumption of transboundary materials, goods and services, the inclusion of scope 3 emissions has the potential to increase the overall emissions footprint of a city. For instance, one study of 79 cities found that emissions increased by 60% when scope 3 emissions were assessed compared to consideration of sector-based emissions only (C40 Cities, 2018). Similarly, another assessment of GHG accounting methods in Copenhagen estimated that consumption-based emissions in 2015 were four to five times higher than production-based emissions (Dahal & Niemala, 2017). In the case of San Francisco, consumption-based emissions were estimated to be 2.5 times higher than sector-based emissions [SF1]. The adoption of consumption-based emission accounting is therefore essential to ensure that frontrunner cities address their total carbon footprint, including transboundary emissions tied to energy use, infrastructure, mobility, goods, and services (Chavez & Ramasawami, 2011; Chen et al., 2019; Ramaswami et al., 2021; Tong & Ramasawami, 2022).

Second, with respect to the lack of economically grounded arguments for pursuing systemic and accelerated decarbonization, this deficiency sits at odds with a host of economic benefits that can result from taking climate action. Such benefits have been confirmed by a study by Gouldson et al. (2018). This review of over 700 studies provides strong evidence of how climate actions like decarbonizing buildings, energy and transport in urban areas can generate positive socio-economic outcomes through job creation, reduced public health expenditures, strengthened social inclusion, and improved accessibility. Of the cities examined in this study, Leeds CAP [LDS1] articulates the clearest economic case for pursuing rapid decarbonization. A decisive factor behind this integration of economic reasoning and climate ambition was the finding from research (Gouldson et al., 2014) that identified how an investment of £4.9 billion in cost-effective measures in Leeds would pay for itself within four years due to savings from improved energy efficiency. Besides Leeds, Copenhagen [CPH3] and San Francisco [SF1] have formally analyzed the benefits and costs of climate mitigation. In the other cities, however, the absence of formal assessments of the economic case for climate action suggests that mitigation measures may struggle to attract investments or funding from non-government sources, such as the private sector (Schwarze et al., 2018). Beyond the cities studied herein, building an attractive economic rationale for pursuing aggressive decarbonization may be particularly important in cities of the Global South where the case for climate action can easily be weakened by rapid population and economic growth (Gouldson et al., 2014).

Third, municipal climate budgets are a relatively new phenomenon, with only Oslo and Copenhagen currently using this mechanism to support CAP implementation. Oslo's efforts are noteworthy since it leverages diverse financial instruments (green procurement, divestment of municipal funds, green bonds, etc.) to support the goal of shifting away from a fossil-fuel economy (Barnhusen, 2019). The limited research on the effectiveness of climate budgets suggests they are critical for spurring decarbonization innovations for two reasons (Vedeld et al., 2021). First, the establishment of a climate budget ensures transparency in money and information flows within the municipal government that are directed at the realization of ERMs. Second, having a pool of dedicated climate funds can serve to align government decision-making with spending and development priorities and helps ensure that public investments facilitate rather than compromise climate goals (Barnhusen, 2019). Given these advantages, it is concerning that four of the case studies analyzed lack dedicated climate budgets.

Finally, recent research has highlighted how a range of innovations in participatory governance work to increase political momentum for faster climate action in cities (Wells et al., 2021). In particular, climate assemblies and juries have been noted for their potential to generate ambitious recommendations going beyond those local political representatives proposed (Wells, 2022). Such participatory governance mechanisms can thus address the tendency for the ambitions of elected officials to be negatively influenced by relationships with industry or by pragmatic concerns about technical or economic feasibility when formulating climate action. Furthermore, integrating the citizenry into climate planning enables creative inputs from a broad array of public voices (King & Wilson, 2022; Sandover et al., 2021) while facilitating policy alignment with societal priorities. Similar observations have been made on the role that participatory budgeting can play in driving climate change mitigation by allowing people to introduce innovative ideas and solutions (Cabannes, 2021). In this context, the finding that CAPs in three cities (Copenhagen, Oslo, and Kyoto) do not refer to participatory governance measures suggests that some cities may not be fully harnessing the potential of citizen engagement when seeking to reduce GHG emissions.

Section 8. Conclusions

This study aimed to conceptualize characteristics and strategies expected to lead to accelerated systemic decarbonization in six cities known for progressive climate policies and then assess the extent to which their CAPs embody these. In so doing, the study addresses the global proliferation of net zero declarations at the sub-national level and the plurality of actions towards this goal. It makes two important contributions. First, the framework deepens the theoretical understanding of socio-technical transitions for deep-cutting and rapid decarbonization in urban settings. Second, empirical analysis of each city's CAP, along with the underlying dataset **(Supplementary Material),** provides an important data resource for scholars and practitioners to deepen their understanding of the climate actions taken by some of the world's more progressive cities as well as gaps and hurdles.

The analysis shows that San Francisco's climate actions are most indicative of accelerated systemic decarbonization. In the other cities, the pursuit of accelerated systemic decarbonization may be hampered by a lack of consideration of scope 3 emissions, limited participatory governance measures, and the absence of economic planning, climate budgets and financial indicators to estimate the benefits or costs of various climate-mitigation actions. By not tackling these areas, several cities fail to fully account for the GHG emissions embedded in consumption and transboundary infrastructures such as transport and electricity grids. Meanwhile, many cities have yet to formulate an economic rationale for the benefits of carrying out rapid and aggressive decarbonization measures. As shown in both San Francisco and Leeds, this can be achieved by formally analyzing the cost and benefit of different kinds of mitigation actions. The climate actions in the cities failing to do so run the risk of being overlooked in favor of actions that maintain or promote carbon-intensive forms of economic development. Meanwhile, the finding that most CAPs lack dedicated climate budgets points to the possibility that local government spending could potentially be undermining decarbonization goals by not focusing on climate mitigation.

Furthermore, the analysis suggests that cities can face a critical choice when formulating decarbonization actions, representing a critical dilemma or trade-off. Should cities aim initially for rapid decarbonization by focused acceleration? This strategy directs resources and policies to a narrow range of sectors (buildings, mobility, electricity, etc.). It leverages the ERMs that provide the greatest return on investment or feasibility from a political, technical, economic, and societal perspective. This may be important in cities with limited resources. Or should cities aim for rapid acceleration via a broader approach aimed at more sectors, including emissions originating from consumer lifestyles? Whichever the choice, after exhausting the low hanging-fruit options—those leading to the largest emission-reduction gains—a need will arise to tackle more complex and persistent residual emissions. Whether a city opts for focused or broader change, systemic acceleration should be anticipated and designed into its strategies sooner rather than later. In this way, climate actions are designed to spur rapid acceleration by tackling entire (or multiple) socio-technical systems rather than specific technologies.

CAPs must serve as an overarching device to tie all major policies and economic activities to the goal of pursuing rapid and wide-reaching decarbonization. Ideally, by creating synergies across different strategies, CAPs would unleash transformative action, whereby the whole transcends the sum of the parts. This potential can be enhanced by initiatives reinforcing the mandate for accelerated action, such as declaring a climate emergency. This said, though each strategy identified in the framework potentially has an accelerating function, the opposite effect could occur if the strategy is poorly designed and implemented. Consider a climate emergency declaration: without follow-up action plans and resources, such a gesture is purely symbolic, and decarbonization is not accelerated. Likewise, innovative participatory governance measures such as juries and assemblies are not a panacea. Rather, they provide opportunities to mobilize the public around net zero objectives and their priorities to decarbonization strategies.

Finally, methodological limitations provide important cues for future research. First, the sample of six cities has merely scratched the surface of diverse CAP activity at the sub-national level. By extending the scope of analysis to more cities, future research could generate a better idea of the nature of municipality-led decarbonization efforts worldwide and deepen understanding of the drivers of and obstacles to systemic and accelerated innovation. There is a need to compare differences in CAP development, implementation, and the degree of acceleration in cities in developing economies with the climate actions of cities in the Global North. Second, the research focused on evidence contained in CAPs and a narrow range of policy documents connected to these. Such evidence could be bolstered by stakeholder questionnaires or structured interviews and by exploring the interaction between urban climate mitigation and the broader environmental policies, measures, and management priorities that cities need to address, which are often dictated by national and international legal frameworks. Third, several questions have escaped the analysis presented in this paper. These include: How do different strategies and system components influence each other, and how can CAPs change these configurations and interactions? What strategies or conditions are most important for achieving accelerated and transformative outcomes at the system level? Does having a near-term target year for reaching net zero raise the likelihood of achieving accelerated systemic decarbonization compared to a city aiming for net zero 2050? This study's small sample (n=6) was insufficient for answering such a question. Finally, city CAPs are continuously evolving. There is thus a need to monitor changes over time to deepen understanding of the fluctuating dynamics of city-level climate policy and the conditions that drive or impede progress to net zero targets.

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