Social Sciences and Humanities Research Council (SSHRC)

Knowledge Synthesis Grant

Living within Earth's Carrying Capacity

Measuring and Managing Living within Earth's Carrying Capacity at the City Scale

A Report by:

Dr. Jennie Moore, Centre for Ecocities, British Columbia Institute of Technology

Dr. Claudiane Ouellet-Plamondon, École de Technologie Supérieure

Christina Olsen, Centre for Ecocities, British Columbia Institute of Technology

Marie Vigier, École de Technologie Supérieure

Dr. Maria Spiliotopoulou, Centre for Ecocities, British Columbia Institute of Technology

Erin Kennedy, Centre for Ecocities, British Columbia Institute of Technology

Leopold Wambersie, Centre for Ecocities, British Columbia Institute of Technology

September 2021

Acknowledgments

The British Columbia Institute of Technology acknowledges that our campuses are located on the unceded traditional territories of the Coast Salish Nations of Sḵwx̱wú7mesh (Squamish), səl̓ilwətaʔɬ (Tsleil-Waututh), and xwməθkwəy̓əm (Musqueam).

The École de Technologie Supérieure (ETS) acknowledges that the *land on which we gather* in Montreal is the traditional and unceded territory of the Kanien'keha:ka (Mohawk), a place which has long served as a site of meeting and exchange amongst nations.

We are grateful for the input by knowledge holders in cities and other communities around the world.

We also wish to thank the project collaborators: Bill Rees, originator of the "ecological footprint" concept and Professor Emeritus of UBC's School of Community and Regional Planning; David Lin, Chief Science Officer of Global Footprint Network; and Alastair Moore, professional planner, co-founder of Greenworks Building Supply Inc., Principal of D&A Planning Inc., and Director of the One Earth Initiative Society.

This project is supported in part by funding from the Social Sciences and Humanities Research Council (SSHRC).

Please note the authors are listed in order of joining the project.

Researcher contacts:

Dr. Jennie Moore, RPP, LEED AP
Director, Institute Sustainability and Centre for Ecocities
British Columbia Institute of Technology (BCIT)
3700 Willingdon Avenue
Burnaby, BC, V5G 3H2
https://commons.bcit.ca/ecocitycentre
Jennie_Moore@bcit.ca

Claudiane Ouellet-Plamondon, P.Eng. M.Sc. Ph.D.
Associate Professor
Canada Research Chair on Sustainable Multifunctional Construction Materials
Department of Construction Engineering
Université du Québec, École de technologie supérieure (ETS)
1100, rue Notre-Dame Ouest
Montréal, QC, H3C 1K3
www.etsmtl.ca
Claudiane.Ouellet-Plamondon@etsmtl.ca

Citation:

Moore, J., Ouellet-Plamondon, C., Olsen, C., Vigier, M., Spiliotopoulou, M., Kennedy, M., & Wambersie, L. (2021). *Measuring and Managing Living within Earth's Carrying Capacity at the City Scale*. Report for a SSHRC Knowledge Synthesis Grant. British Columbia Institute of Technology (BCIT) and École de technologie supérieure (ETS).

Table of contents

List of Figures

List of Tables

Executive Summary

Background

Most of the global population lives in cities and this urbanization is expected to increase. Meanwhile, high-income societies, like Canada's, are responsible for year-over-year increases in global demand for energy and material resources. This demand exceeds Earth's carrying capacity (ECC), defined as the total number of people that can live within the regenerative and assimilative capacities of nature. A handful of high-income cities are reporting absolute reductions in greenhouse gas emissions across their entire community, even with continued population growth. These cities represent a learning opportunity for understanding how we can live within ECC.

Objectives

The purpose of this research synthesis and critical analysis is to accelerate the knowledge transfer to Canadian cities about effective urban measurement and management frameworks, governance models, and policy implementation for living within ECC, by studying how high-income cities are achieving absolute reductions in energy and material throughput. Investigations into alternative knowledge systems and development pathways are also explored to expand the scope of opportunity for effective action beyond conventional paradigms and approaches.

Methodology

The grey and academic literature were surveyed in English and French for the period 2010 to 2020. Publications from early 2021 were also included and publication counts for some key word searches were extended back to 1990 for historical comparison. Two themes guided the research: Theme 1 addresses the sustainability frameworks and metrics cities are using to measure progress and Theme 2 addresses the governance models and policies cities are implementing to mitigate their ecological impacts. Taken together, these themes inform how cities are measuring and managing the challenge of living within Earth's carrying capacity. A sub-theme focused on high-consuming cities that are reporting absolute reductions in greenhouse gas emissions over the study period. A second sub-theme explored knowledge systems and development pathways that are alternative to the more common approaches in an attempt to gain additional insights into Indigenous knowledge perspectives as well as approaches employed by low-income cities in the Global South. Symposiums were held to discuss findings with project collaborators. Interviews with key knowledge holders in leading cities in Canada and around the world provided additional insights, particularly with regard to questions about cities achieving absolute emissions reductions, policy, governance, and alternative knowledge systems.

Results

Sustainability is a concept not commonly framed as living within ECC. Out of 31 sustainability frameworks identified in the literature, only 11 align fully with the goal of living within ECC. Awareness about the value of reporting on global impacts is increasing. Cities appear to be working with many sustainability frameworks and tracking multiple indicators. However, with the exception of greenhouse gas emissions, few cities are working with metrics tied to global, ecological carrying capacity, such as ecological footprint analysis. In the 2010-2020 period, cities found achieving absolute reductions in greenhouse gas emissions (GHGs) were located in North America, Europe, and Asia. These are also the dominant global emissions producers. Greenhouse gas emissions reporting, however, is typically constrained to territorial inventories

that focus only on local resource and pollution flows, thereby underestimating a city's total impact. Consumption-based greenhouse gas emissions inventories that include life cycle assessment impacts of products in supply chains and out-of-boundary travel can provide new information to cities and a growing number of cities are aware of the need to change GHG accounting methods.

The literature connecting governance and city policy implementation is evolving with a majority of authors coming from Europe and Asia, particularly China. Cities implementing innovative and/or ambitious policies are not necessarily reporting on performance outcomes. This represents an important gap. Cities achieving absolute greenhouse gas emissions reductions use many policy tools; however, the literature does not reveal a marked departure from other cities who are identified as sustainability leaders using similar policies but who are not achieving similar results. This implies that other contextual factors, such as regional or state government, community, and local business actions play a contributing role. Interviews with knowledge holders in cities achieving absolute emissions reductions identified a culture of commitment by elected leaders within the city and at senior government levels, adequate resourcing to achieve explicit targets, and a focal point for accountability such as a sustainability or climate office, complemented by leadership and support across municipal planning, engineering, and other departments. Use of a full suite of regulatory measures was also reported by knowledge holders but not detected in the literature, which instead emphasized educational and incentive approaches.

Key Messages

- Most cities studied are not working towards a goal of living within Earth's carrying capacity.
- Cities currently focus their sustainability efforts predominantly on climate mitigation and adaptation through resilience.
- None of the studied cities' emissions reductions are sufficient to achieve climate stability.
- Cities continue to invest a majority of their resources in perpetuating unsustainability.
- Most of the studied cities report confidence in achieving their climate target goals but not living within Earth's carrying capacity.
- Policy coherence among multiple levels of government and with global actors can help enhance municipal decision-making processes and achieve sustainability.
- Changes in political leadership at all levels result in discontinuous pursuit of sustainability goals.
- Good governance and capacity-building ensure that city measurement and evaluation efforts are conducted effectively, consistently, and transparently.
- Planning processes should be integrated and comprehensive enough to work within the complexity of relationships among natural and human designed systems, and that public engagement is appropriately participatory.
- Greater focus on root causes of unsustainability, what sustainability requires - including the energy and material inputs and outputs relative to Earth's carrying capacity - and how to move forward is urgently needed.
- Alternative perspectives and pathways – such as Indigenous knowledge, regenerative design, and approaches used in the Global South – are long-standing but not part of the dominant narrative.

The implications of inequitable distribution of cost-bearers and benefit-takers regarding global sustainability challenges are surfacing as an evident priority. There is increasing recognition that averages mask the reality of medians. For instance, the wealthiest 10% of the population is responsible for half of global of GHG emissions; the top 1% wealthiest create twice the emissions as the poorest half of humanity.

A small number of people have an outsized negative impact; this extreme wealth tremendously compromises the global population's ability to live within Earth's carrying capacity. And yet, economic growth remains a paramount objective for most cities. This goal is frequently divorced from recognition that at current levels of energy and materials throughput, cities are living beyond Earth's carrying capacity. Most sustainability frameworks undermine the potential for city success by remaining untethered to global ecosystem stability thresholds. Attempts to improve efficiency or achieve circularity must be reconciled to the magnitude of reductions needed in current consumption and waste outputs by high consuming cities to achieve living within Earth's carrying capacity. Assessment of investment across all municipal departments is recommended to determine how much of it maintains unsustainable infrastructure systems and whether long-term ecological and social costs are being factored into operating decisions. Policy alignment across departments is recommended to identify and implement alternative ways of servicing city needs.

1. Background

Scientists have informally coined this era as **the Age of the Anthropocene**. A time when humanity has become the dominant force in determining Earth's ecological trajectories (Steffen et al., 2018). Unlike the preceding Holocene, the Anthropocene represents an era of disruption and uncertainty in which humanity is reshaping Earth's ecosystems by systematically transforming wilderness into agricultural, industrial and urban landscapes, directly impacting over 70% of Earth's ice-free land area (IPCC, 2019).

This trajectory of human exploitation of Earth's resources is accelerating. For example, over the last 70 years, humans have transformed half the Earth's total habitable land from the wilderness to agriculture (Ritchie & Roser, 2020). Over the last 50 years, global raw timber harvest has increased 45% (Brondizio et al., 2019). For the coming decade, the International Energy Agency is forecasting 30% growth in fossil fuel consumption (International Energy Agency, 2019). While some countries are increasing the economic value-added per kilowatt hour (kWh) of primary energy, it is not the case everywhere and in many places an increase in GDP still means an increase in carbon dioxide (CO_2) emissions (Jancovici, 2017). Global emissions have been increasing for decades, in large part because many nations have been offshoring their industrial emissions to emerging countries using more carbon intensive carbon sources (Levitt et al., 2019). Developed nations are still having difficulty in reducing their emissions at the level needed for the Paris Agreement target of keeping global temperature rise to 1.5 C above pre-industrial levels, which requires major lifestyle changes (Institute for Global Environment Strategies et al., 2019). Moreover, global human-made mass now exceeds living biomass on the planet; buildings and infrastructure represent 1,100 gigatonnes (Gt), while trees and shrubs represent 900 Gt; plastic represents 8 Gt, while animals represent 4 Gt (Elhacham et al., 2020).

Humanity is in a state of global ecological overshoot. This means that annual demand for natural resources to support the human enterprise exceeds what nature can produce on a sustained yield basis (Global Footprint Network, n.d.-b; Rees, 2020). Among other symptoms triggered by this unprecedented situation are rapid climate change and the sixth mass extinction of species (Almond et al., 2020; Brondizio et al., 2019; Lewis & Maslin, 2015). Responses from the global scientific community have been firm and consistent for over thirty years, calling for absolute reductions in the amount of energy and materials consumption in the global economy by up to ten-fold (Meadows et al., 1972; Millennium Ecosystem Assessment, 2005; Rees, 2020; Ripple et al., 2017; von Weizsäcker et al., 2009).

Accumulating evidence of accelerating and unavoidable impacts from climate change is spurring a global consensus for massive reduction in greenhouse gas emissions and regeneration of natural ecosystems. We need to protect ecosystems and their services on at least 30-50% of global lands, compared to around 16% protected today (Marris, 2019). The Intergovernmental Panel on Biodiversity and Ecosystem Services identifies the largest drivers of nature change as: i) changes in land and sea use, ii) exploitation of organisms, iii) climate change, and iv) alien species invasion. The indirect drivers of these phenomena are underpinned by societal values and behaviors manifested through: i) production and consumption patterns, ii) human population dynamics, iii) trade, iv) technological innovation, and v) local through global governance (Brondizio et al., 2019).

In a state of extended ecological overshoot, as is the case today, there is no room for half measures if sustaining a "good quality of life for all" is the goal**. Economic and political activity continues to entrench a system where Earth's resources are being liquidated faster than they can be regenerated, and the**

majority of the money wealth being created through these activities concentrates in the hands of a minority of the global population. The world's richest 1% owns 43.4% of global wealth while 53.6% of global population hold just 1.4% of global wealth (Shorrocks et al., 2020). In addition, the wealthiest 10% account for at least 48% of global emissions and the bottom 50% account for only 7% of global emissions (Barrau, 2019; UNEP, 2020).

Simultaneously, **the scale of the global economy has reached dis-economic proportions**, meaning more economic growth causes more problems than it solves. Efficiency and economic decoupling from resource use/extraction in an attempt to conserve resources are undermined by a rebound effect, because the energy and material savings are ploughed back into more economic growth instead of invested in ecological regeneration; with state actors still committed to economic growth agendas (Mathis, 2018). Compounding this challenge is the fact that for every dollar that trickles down, at least five flow up into the hands of those who already hold the majority of global wealth. For instance, averages mask the reality of a declining median income for average workers. Globally, new middle-class communities are emerging, largely as a result of progressive economic distributive policies rather than an automatic outcome of trickle-down economics.

The Anthropocene is also a period of global urbanization. The majority of people now live in cities and this trend is expected to continue (United Nations, 2019). The urbanizing world positions cities at the nexus of inquiry into how humanity can adapt to living within Earth's carrying capacity (Baabou et al., 2017; Lombardi et al., 2017; Moore et al., 2013; van der Heijden, 2019). **Ecological carrying capacity is defined as the total population of a particular species that can be supported by a specific, biologically productive area;** this is the limit of anthropogenic pressure that our ecosystem can sustain without irreversible degradation (Świąder, 2018)**.**

Although cities provide an efficient space in which the majority of the global population lives, from an ecological perspective, cities, and the people and economies operating within, are dissipative structures (Rees, 2012). They rely on energy and material resources, appropriated from nature, as inputs to their structural evolution and operation. Cities account for approximately 75% to 80% of material and energy flows and associated greenhouse gas emissions (Dong et al., 2016; Ghaemi & Smith, 2020; Hachaichi & Baouni, 2020; Harris et al., 2020; Lombardi et al., 2017; Moore, 2015; Swilling et al., 2018). Fueled by fossil energy, enabled by technology, and supported through global trade, cities are designed, constructed, and operated assuming a continuous flow of available resources that enter as consumable goods and exit as wastes (Bihouix, 2019).

Although cities cover approximately 1% of Earth's habitable land (Ritchie, 2019), the ecologically productive area needed to sustain them has been estimated at 30 to 200 times this amount (D'Amour et al., 2017; Folke et al., 1997; Moore & Rees, 2013). Half of the world's population lives in urban areas and this is projected to increase to 70% by 2050, with 90% of this growth happening in Africa and Asia (United Nations, 2019). This strong urbanization trend suggests a growing pressure exerted by cities on natural assets, threatening to increase the vulnerability of urban systems that are already fragile in terms of food security and resilience (Hueston & McLeod, 2012; Jensen & Orfila, 2021).

Canada's richness in land and resources means it will face growing immigration pressures from regions experiencing severe ecological constraints. The federal and local governments in Canada must therefore have management and policy tools in place to address carrying capacity based not just on current resource use, but also from growing demand.

Participation by local stakeholders, particularly those most vulnerable to potential impacts, improves decision-making and governance for policy selection, implementation, and monitoring (IPCC, 2019). Unfortunately, the dominant paradigm driving global human evolution for at least the last 70 years operates at cross-purposes to the goal of living within Earth's carrying capacity (Rees, 2020). Since the end of World War II, the dominant paradigm shaping human behaviour has been predicated on stimulating employment and economic growth as a preferred means to create and distribute resources needed for human survival. Historical assumptions about ecological and social costs of economic activities and a faith in the potential for human innovation to solve for any eventual challenges has assuaged concerns about ecological limits (Barbier, 1987; Meadows et al., 1972; Solow, 1993). The result is a massive, global urban enterprise locked-in to an economic structure that supports urban activities in built-environments that are unsustainable. The inertia within these systems to adapt to scientific predictions, and subsequent arrival of unprecedented global and ecological change presents significant challenges.

Nevertheless, **a handful of cities are achieving absolute reductions in their total energy and materials use, despite continued population growth**. Although their achievements are modest, at less than 10% reduction on average, these cities represent a window of opportunity to learn about how to adapt to the challenge of living within Earth's carrying capacity. This report investigates what factors contribute to this outcome by exploring the intersection between i) measurement and evaluation frameworks for living within Earth's carrying capacity and ii) the governance and policy strategies employed by local governments in high-consuming cultures that have successfully used them to achieve absolute reductions in consumption or waste outputs that include greenhouse gas emissions.

1.1. Theme 1: Measures and Evaluation Frameworks for Sustainable Cities

Evaluation frameworks to measure living within Earth's carrying capacity (ECC) are proliferating. Generally, frameworks bring goals and actions together and provide a means for tracking progress (Sala et al., 2015). This synthesis starts by identifying the characteristics of a framework for alignment with living within ECC. Frameworks can gauge human demand for Earth's resources and related ecosystem services against stability thresholds represented by nature's capacity to generate those resources and assimilate wastes to be more aligned with ECC. Some provide added utility by being able to identify hot spots or specific issue areas that account for substantial impacts, indicating their priority for management attention. Examples include: biocapacity measures, such as the ecological footprint and planetary boundaries; resource measures, such as the material footprint and water footprint; and waste sink measures, such as the carbon footprint (Čuček et al., 2012; Patterson & Coelho, 2009; Rees, 2012; Rockström et al., 2009; Steffen et al., 2015; Swilling et al., 2018; Wackernagel & Rees, 1996; Wiedmann & Minx, 2007). In every case, the magnitude of change needed to transition from the current state of overshoot to a state operating within Earth's carrying capacity is considerable (Institute for Global Environment Strategies et al., 2019; Moore, 2015; Moore & Rees, 2013; Swilling et al., 2018; Waridel, 2019).

A few data sources allowed a better understanding of the fundamental properties of city systems (Bourdic et al., 2012; Cura et al., 2017; Rees, 2012). Urban studies often focus on specific environmental indicators and include social justice considerations (Audrin et al., 2020; Carrier et al., 2019; Jancovici, 2017; Pham et al., 2017). Several measurement tools are gaining global recognition, such as: the United Nations (UN) Sustainable Development Goals (United Nations, 2015); Planetary Boundaries (Rockström et al., 2009; Steffen et al., 2015); the 'safe and just space for humanity' advocated by Doughnut Economics (Raworth,

2017); Ecological Footprint Analysis (Isman et al., 2018; Moore et al., 2013; Wackernagel et al., 2013; Wackernagel & Rees, 1996); Greenhouse Gas Protocol for Cities (World Resources Institute et al., 2014); International Organization for Standardization's ISO 37120:2018 Sustainable cities and communities (ISO, 2018); and International Ecocity Standards (Moore et al., 2019), to name a few.

However, there is substantial variation across the frameworks for what gets measured, and when it comes to assessing living within Earth's carrying capacity, not all frameworks are created equal. A singular focus on one issue, for example greenhouse gas management, may inadvertently create a rebound effect. This may create new challenges in different and unforeseen areas, for example producing crops for fuel instead of food risks unanticipated challenges to food security. This speaks to a need in urban sustainability management for a broad and holistic perspective. Absolute reduction of impacts by cities is needed to change the course of resource depletion. Frameworks and metrics, such as energy and material flow analysis, must guide the cities on the path of absolute reduction.

1.2. Theme 2: Governance and Capacity-Building

Managing a community to enable living within Earth's carrying capacity requires more than understanding ecological, social, and economic impacts. It includes a range of institutional aspects that contribute to robust implementation at the city level, both by city agents and collectively by its populace. This requires agreement on whether and how to work with sustainability metrics and how to effectively translate them into policy actions.

Although cities lack jurisdictional authority for major drivers of economic activity, they have flexibility to act in the interest of their resident constituents. Indeed, over recent decades, cities have proved to be more willing and able than central governments to lead on climate action and on efforts to enable people to live sustainably. The international city network C40 Cities reports on 26 cities around the world whose greenhouse gas emissions peaked by 2012 with subsequent absolute reductions in greenhouse gas emissions by at least a 10% in the following five years (C40 Cities, 2018). Several have made public commitments to living within global ecological carrying capacity. Nevertheless, of the few cities that have declared a policy goal to live within Earth's carrying capacity, fewer still have made progress. However, where progress is being made, the literature and relevant knowledge holders can offer important insights relative to what factors and policies are enabling effective action and outcomes (Baabou et al., 2017; Isman et al., 2018).

Good governance and capacity-building ensure that city measurement and evaluation efforts are conducted effectively, consistently, and transparently; and that planning processes are integrated and comprehensive enough to work within the complexity of relationships among natural and human designed systems, and that public engagement is appropriately participatory. Examples of cities with ambitious sustainability goals, but lacking proper governance is becoming too frequent. For example, in Dongtan, China a self-sufficient "eco-city" failed due to lack of a well governed participatory approach (Öjendal & Dellnas, 2010). On the flip side, a strong participatory public engagement process in Durban, South Africa was not matched with adequate capacity or authority which impeded the implementation of sustainable practices (Williams, 2006). In Brazil's Favela Bairro, a revitalization program failed due to governance problems, namely lack of monitoring and community information, guidance, and participation (Tigre, 2015).

Governance is a critical aspect of city sustainability (Science for Environment Policy, 2018). Cities having ethics and equity as core values must address sustainability and the climate crisis as core concerns throughout efforts to act on governance, democracy, social inclusion, poverty, and inequality (Barrett et al., 2020). Governance directly affects organizational and societal outcomes, encompassing authority, decision-making, and accountability. Strongly linked with the concept of governance is capacity-building, which is the process by which the skills, knowledge, and other resources needed to fulfill the city's goals are obtained, created, and retained. With the increasing reliance on data to inform decision making in the urban sector, appropriate governance and capacity-building facilitates the human and institutional resources needed to tackle the massive local and global challenges we face (Courmont & Le Galès, 2019).

1.3. Sub-Theme: Leadership by Cities and Communities Achieving Absolute Reductions

Cities and their citizens are becoming increasingly interested in the question of how to live within Earth's carrying capacity (Kennedy et al., 2011; Rees, 2013), as also demonstrated by the theme of the SSHRC Knowledge Synthesis Grant program. As the impacts of climate change are becoming understood, many cities have declared a climate emergency, and a handful are achieving absolute emissions reductions (C40 Cities, 2018). Although no city has successfully transitioned to socio-ecological sustainability, several are reducing energy and materials throughput, despite simultaneous population increase. Exploring what factors contribute to this outcome is a priority.

1.4. Sub-Theme: Alternative Knowledge Systems and Development Pathways

Indigenous people have other systems of thinking to describe living within Earth's carrying capacity, such as mino-pimatisiwin offering resilience and healing by traditional practice (Landry et al., 2019). A quarter of Earth's land area is traditionally owned, occupied, used or managed by Indigenous peoples, and nature is declining less rapidly in these places (Brondizio et al., 2019). A key aspect of these knowledge systems is that they are highly place-based and distinctively relevant to local and regional contexts. They are aligned with the ecological, living systems worldview that promotes ecosystem regeneration, equity (not only among humans but also with nature), and engagement in co-evolutionary processes (Spiliotopoulou, 2021).

Indigenous ways of knowing are rooted in concepts of interconnection where the relationship of humans to their world offers acknowledgement of ecological reality and traditional feedback systems for managing human activity within it (Wahl, 2016). Indigenous and non-Indigenous communities, particularly in the Global South, have been demonstrating leadership in pursuing alternative development pathways that prioritize for example local self-reliance, food security, socio-ecological resilience, and open public spaces (Vodden et al., 2016). In such geographic regions, literature on absolute reductions may be under-represented because the focus may instead be on securing essential resources to sustain minimum livelihood conditions or ensuring the preservation and regeneration of critical biodiversity and habitats.

2. Objectives

The purpose of this research is to accelerate the knowledge transfer to Canadian cities about effective measurement and management frameworks and policies for living within Earth's carrying capacity. The research focus is directed towards understanding how a handful of cities around the world are achieving absolute reductions in energy and material throughput and how this might be translated into policy and action in Canadian cities. Attention is also given to alternative approaches to achieve sustainability as represented in Indigenous or alternative development pathway literature and knowledge holder perspectives.

The following research questions guided the inquiry and findings for this report:

1. How are cities approaching measuring and managing for living within Earth's carrying capacity?
    a. What frameworks and metrics are they using?
    b. What governance models do they operate within?
2. What factors contributed to the success of cities that have intentionally achieved absolute reductions in their material, carbon, or ecological footprint?
    a. Are cities using sustainability frameworks and metrics to measure progress towards the goal of living within Earth's carrying capacity?
    b. Which cities have achieved the most reduction in the 2010-2020 timeframe?
    c. Are cities achieving absolute reductions aligned with the goal of living within Earth's carrying capacity?
    d. What policies are they implementing?
3. What governance models and policy implementation strategies have proven to be most effective?
4. What alternative approaches and development pathways present potential solutions?

The objectives for the project include:

- Assessing and summarizing the state of knowledge and gaps from a variety of academic and practitioner sources in Canada and around the world;
- Assessing data availability and the quality, accuracy, and rigor of current work in the field;
- Mobilizing knowledge by engaging with a variety of stakeholders across disciplines and sectors to ensure a diversity of perspectives;
- Identifying the most promising combinations of measurement and management for policy and practice and areas for further research.

Specifically, we examine the ways in which cities are measuring and managing their activities in relationship to established global ecological thresholds for energy and materials consumption relative to global ecological bio-productivity. Two themes guide the research: Theme 1 addresses the frameworks and metrics cities are using. Theme 2 addresses the governance models and policies cities are working with. Taken together, these themes inform how cities are measuring and managing living within Earth's carrying capacity.

The synthesis incorporates a critical review of sustainability evaluation frameworks and metrics aimed at helping cities and their citizens live within Earth's carrying capacity. It combines this with an assessment of governance and policy measures to determine factors that contribute to the ability by local government to use these tools effectively to mobilize social transformation. The necessary evidence is proof of

intention by cities to achieve a stated goal of living within Earth's carrying capacity combined with effect action, measured by an absolute reduction in demand for nature's services.

Through the research we identified patterns of commonality, unique approaches, as well as gaps. We interviewed knowledge holders from cities and communities that are leading in sustainability efforts in an attempt to fill knowledge emerging knowledge gaps identified in the literature. We also gleaned new insights to answer the question of how cities can operate within, and help their citizens to live within, Earth's carrying capacity.

3. Methods

3.1. Overall Search Methods

A mixed methods research design was used, integrating quantitative and qualitative data. Literature in both English and French were reviewed. Definitions for the keywords used to guide the research were confirmed based on the researchers' familiarity and knowledge with established literature in the field (see Glossary in Appendix A). The web search platforms used were Scopus, Web of Science, Google Scholar, Semantic Scholar, and Google, as well as the search engines of our academic institutions' libraries.

Search methods comprised a review of the published academic literature spanning the period 2010 to 2020 for each theme, supported by an exploration of grey literature representing field activities. This included investigation of program databases, reports, and other data outputs such as maps issued by government and non-government organizations. The most relevant and the most cited articles were selected. Additional literature written and/or published in early 2021 was subsequently included to benefit from new insights in this rapidly emerging field. Keyword searches were then expanded using an iterative approach. Emerging gaps, for example with regard to geographic representation by author and study focus, also were subsequently used to direct additional searches using new keywords.

Additional qualitative data and insights were collected through a participatory process with project collaborators and knowledge holders in cities identified through our literature review. One collaborator symposium took place in the fall 2020 and another in the spring 2021. Key knowledge holders, such as city officers responsible for sustainability activities and traditional knowledge holders representing alternative perspectives, were subsequently engaged in structured interviews.

3.2. Data Collection and Analysis

3.2.1. Theme 1 – Frameworks and Metrics

The research on frameworks and metrics was conducted in four stages in an iterative way. In the *first* stage, an initial list of frameworks was compiled based on previous research by the team members and an investigation of cities engaged in initiatives utilizing sustainability frameworks and metrics. In the *second* stage, the search platforms mentioned above were used to identify more frameworks and related academic and grey literature. Keywords and phrases included: sustainability framework, sustainable development, global sustainability, urban sustainability, sustainable cities, ecological limits, urban metabolism, ecocities, carrying capacity, sustainability methods / tools / metrics, ecological sustainability, urban performance assessment, urban resilience, and material flows.

Because we are interested in cities that are intentionally finding ways to operate within Earth's carrying capacity (ECC), in the *third* stage the frameworks were evaluated based on whether they explicitly articulated a goal of living within ECC and whether they included pathways to achieve the goal with metrics to measure progress. Criteria for measuring absolute reductions in energy and material consumption in cities were categorized in five domains: food, buildings, consumables and waste, transportation, and water.

For the *fourth* stage, the research on sustainability metrics started with a review of cities that are working with their carbon footprints and a search of databases and reports published by various cities and non-governmental organizations (NGOs) to identify those participating in various climate mitigation initiatives.

Metrics were also identified in the academic literature based on whether they would allow measurement of consumption relative to established ecological carrying capacity thresholds for Earth.

To complete the data collection for Theme 1, all annotated literature was organized and summarized in bibliography format with summary tables (Appendix D). These tables include information such as the degree of alignment with living within ECC, the geographic origin and organizational status of the author(s), and the geographic location of the study, framework, or tool. Lastly, we looked for evidence of cities engaging with only the frameworks that align with the goal of living within ECC.

3.2.2. Theme 2 – Governance and Policy Implementation

Governance

The primary questions in Theme 2 are what governance models (formal and informal) are in place where cities have been making progress towards their goals of living within Earth's carrying capacity, and what policies have been implemented? The literature search was conducted using the online databases Web of Science and Scopus. Additional articles were added by following up on citations in articles identified as key resources. The literature review involved three steps.

First, we identified the different governance models that are used in the literature. An exploratory literature search was conducted using the term "Governance" in iterations with the research proposal's key words: "Sustainable Cities"; "Ecological Limits"; "lifestyles"; "Earth's carrying capacity". From this search we identified the most common models of governance appearing in the literature, as presented in the Results section below.

Second, we scanned the literature (primary literature review) seeking to understand if/how cities use the governance models toward the goal of living within Earth's carrying capacity. It is important to note that this goal was not a phrase or concept frequently used in the literature (further explored in the supplementary literature search). This review initially resulted in hundreds of articles but not all were closely enough related to the research topic to be considered. We reduced these to a focused list by looking for articles referring to the identified governance models and including the research proposal's key words. This resulted in approximately 120 articles which were read and curated to create an annotated bibliography of 37 articles that provides an understanding of the topic (Appendix E).

Third, we conducted a supplementary literature review focused on the concept of local governance in combination with the research proposal's key words. From this literature search, a total of 28 English language resources between the years 2010-2021 were found. The total number did not change when the search was opened to include all years of publication, indicating that these search terms are relatively new and emerging within academic literature.

Policy Implementation

Urban policy profiles were developed for both the cities identified by our analysis, and for a broader, globally representative sample of cities. This exercise was used to gain an understanding of the trends in contemporary real-world urban policymaking, as opposed to trends in subjects covered by academic literature, and to provide a reference database for the project. The city policy profiles were structured as a table and organized by global region as well as by whether the city was identified as exhibiting absolute reductions in emissions. Each profile included space for relevant information about the city's governance structure, geographic and historic context, and whether the city is best known for the implementation of

a particular type of urban policy. Information about each city's policymaking was categorized by domain (key plans, transportation, buildings and energy, food and consumables, waste, water), and by the nature of the policy (education, incentive, regulation, capital project).

Research on each city's urban policymaking was conducted using a hybrid approach which included: a survey of the academic literature, internet search for media impressions, consultation of city government websites, and consultation of independent databases and organizations such as C40 Cities, World Green Building Council, Green Growth Knowledge platform, among others. A summary of sources can be found in Section 4.2.3. Research was conducted both systematically, for each city, as well as via a 'snowballing' review method. Additional information was contributed by the knowledge holder interviews.

This approach delivered a high-level understanding of the state of policymaking in a sample of global cities. Nevertheless, it was limited by the fact that most policies adopted by cities, if they fall outside the narrow set of policies deemed noteworthy or controversial, are adopted quietly and are difficult to identify without a substantial amount of pre-existing contextual knowledge.

3.2.3. Sub-Theme: Leadership by Cities and Communities Achieving Absolute Reductions

The identification of leading cities was an iterative process: we first selected cities throughout the globe for their action and success on environmental issues. To limit the scope of research, we looked for cities that met criteria for achieving absolute reductions in energy and materials consumption and associated waste outputs using metrics that are calibrated to global ecosystem stability thresholds. We thus selected four primary metrics that are well established in the literature and represent the general boundary conditions for living within ECC: material footprint, carbon footprint, ecological footprint, and water footprint (Bringezu, 2015; Gleeson et al., 2019; Institute for Global Environment Strategies et al., 2019; Kissinger & Stossel, 2019; Li et al., 2020; Paterson et al., 2015; Rockström et al., 2017; Swilling et al., 2018; Wackernagel & Rees, 1996).

As there is no single indicator that can measure sustainability and ECC as a whole (Baabou et al., 2017; Liu et al., 2020), we used three main criteria to select cities leading the way towards living within ECC:

1) Absolute reduction in terms of greenhouse gas emissions and carbon, materials, energy, waste production, and ecological footprint (*absolute* – as opposed to *per capita* – reduction helps account for population changes);
2) Intentionality, meaning that reductions must result from policies (i.e., voluntarily) and not from natural hazards, economic cycles, or disrupting events such as the COVID-19 pandemic – a proxy for intentionality is the stated use of one or more ECC-aligned frameworks; and
3) Reductions must have taken place between 2010 and 2020, so as to keep this research consistent with the contemporary urban context.

Data were collected from various sources to increase geographical representation and get a broad overview of leading cities worldwide. Because of greater accessibility of data, cities were shortlisted based on ecological footprint analysis (EFA) or carbon footprint analysis (CFA). The main sources included the Carbon Disclosure (CDP) Database, the Carbon Neutral Cities Alliance (CNCA), the C40 Cities Climate Leadership Group, municipal web platforms, Global Footprint Network (GFN), and World Wide Fund for Nature (WWF) studies. We also conducted a broad literature review to map the existing urban ecological footprint assessment and identify longitudinal studies in the period 2010-2020 and we recorded

information such as the type of assessment (e.g., top down or bottom-up) and the ecological footprint in absolute and per capita terms.

As the research progressed, we documented the names of cities using or participating in sustainability frameworks that align with ECC and also achieving absolute reductions according to the selected metrics. We catalogued the cities according to which and how many sustainability frameworks and metrics they are using and the level of reductions in resource consumption and/or waste outputs they were achieving. For carbon footprint, the indicator for which the most data were accessible at the urban scale, we organized the cities according to their level of engagement, represented by the "Scope" of emissions they were addressing, e.g., BASIC (Scope 1 which covers direct emission from owned or controlled sources, plus Scope 2 which covers indirect emissions from the generation of purchased electricity, steam, heating, or cooling), BASIC+ (Scope 1 and 2 and part of Scope 3 which are other indirect emissions upstream and downstream of a city's activities, such as purchased goods and services, travel, and transport). We then looked for evidence of cities that had quantitatively reduced their greenhouse gas emissions. We then narrowed down further, by extending the temporal scope to the earliest baseline available, to only keep the best performing cities and find a balance between rigorousness and inclusiveness. Shortlist 1 contained the cities fitting these three criteria and shortlist 2 contained other exemplar cities and Canadian cities.

3.2.4. Sub-Theme: Alternative Knowledge Systems and Development Pathways

Alternative knowledge and development pathways identified in Indigenous, non-Indigenous, and Global South communities offer possibilities for the management of cities within Earth's carrying capacity. How these pathways and knowledge are – or might be – practiced at an urban scale in other locales or in non-Indigenous communities, for example in the Global North, is an area for greater exploration.

For this sub-theme, we looked for narratives of engagement in thinking and practices outside of conventional sustainability approaches and sought to understand what communities that move toward the outcome of living within ECC do differently. We revisited our literature search using alternative pathways keywords to build knowledge both on alternative pathways conceptually and on specific examples of cities embracing pathways such as holistic resource productivity and ecological regeneration. Particularly acknowledging that ecological regeneration is also a strategy for achieving living within Earth's carrying capacity, we also reviewed literature pertaining to urban, bio-productive strategies aimed at rehabilitating natural areas and supporting biodiversity.

While most pathways were identified in academic and non-academic literature, several practices and initiatives were the result of online research. Key words used included "ecological restoration or regeneration", "regenerative practices", and "socially and/or culturally inclusive innovation", and the selection criteria included "application in urban settings", "guided by theories underlying alternative pathways", and "having proved or potential impact on multiple community dimensions". This line of inquiry additionally targeted the geographic regions where literature on absolute reductions was underrepresented and where the focus may instead be on securing essential resources to sustain minimum livelihood conditions or ensuring the preservation and regeneration of critical biodiversity and habitats.

3.2.5. Key Knowledge Holders' Input

Based on gaps identified in the literature, we developed a questionnaire to collect more information from key knowledge holders working at the city level. The leading cities achieving absolute reductions were identified as explained in 3.2.3 above. Tokyo was also selected as an exemplar Asian city achieving reductions and Belo Horizonte in Brazil was selected as a leading South American city. Canadian cities included leading cities, with others added to ensure representation from coast to coast. Contact details of key knowledge holders were identified through internet search and personal contacts.

Interviewees were invited by email and sent the consent form and project questionnaire in advance of the interview. Each interviewer completed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics[1] in advance of contacting knowledge holders. The 1.0-1.5-hour interviews were conducted via Zoom and were based on the questionnaire. A written summary was compiled after each interview. One city answered a short version of the questionnaire in writing in lieu of an interview due to language translation challenges.

3.2.6. Research Limitations and Gaps

Despite the wealth of knowledge presented in this report, this research also encountered some obstacles and revealed some limitations. The first was the sheer abundance of literature on the topic of measuring and managing urban sustainability and living within ECC. We identified hundreds of academic and non-academic pieces of literature in English and French and had to set specific criteria to narrow the scope down to those that would offer a substantial contribution to this knowledge synthesis. A second limitation relates to the dearth of literature on Indigenous, Global South, and alternative pathway communities; these are barely visible in the urban sustainability literature and in databases, resulting in both lack of inclusiveness and difficulty in connecting such low-consuming communities with frameworks and practices. Finally, the unavailability of information for some regions or cities biased the results against the least transparent cities, those not using a systematic process of measuring and managing, and those absent from related literature or case studies.

[1] Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans – TCPS 2 (2018): https://ethics.gc.ca/eng/policy-politique_tcps2-eptc2_2018.html

4. Results

4.1. Theme 1 – Frameworks and Metrics

4.1.1. Overview of Literature on Living within ECC

The review of literature on living within Earth's carrying capacity, based on sets of key words provided in the original research proposal (definition of search terms is in the Glossary), showed correlation between terms used and location of authors. As Figure 4-1 shows, European and North American authors have published more on Earth's carrying capacity for cities, whereas Chinese authors have published more on ecological carrying capacity for cities. There is some overlap between this literature review and that for the sustainability frameworks presented below.

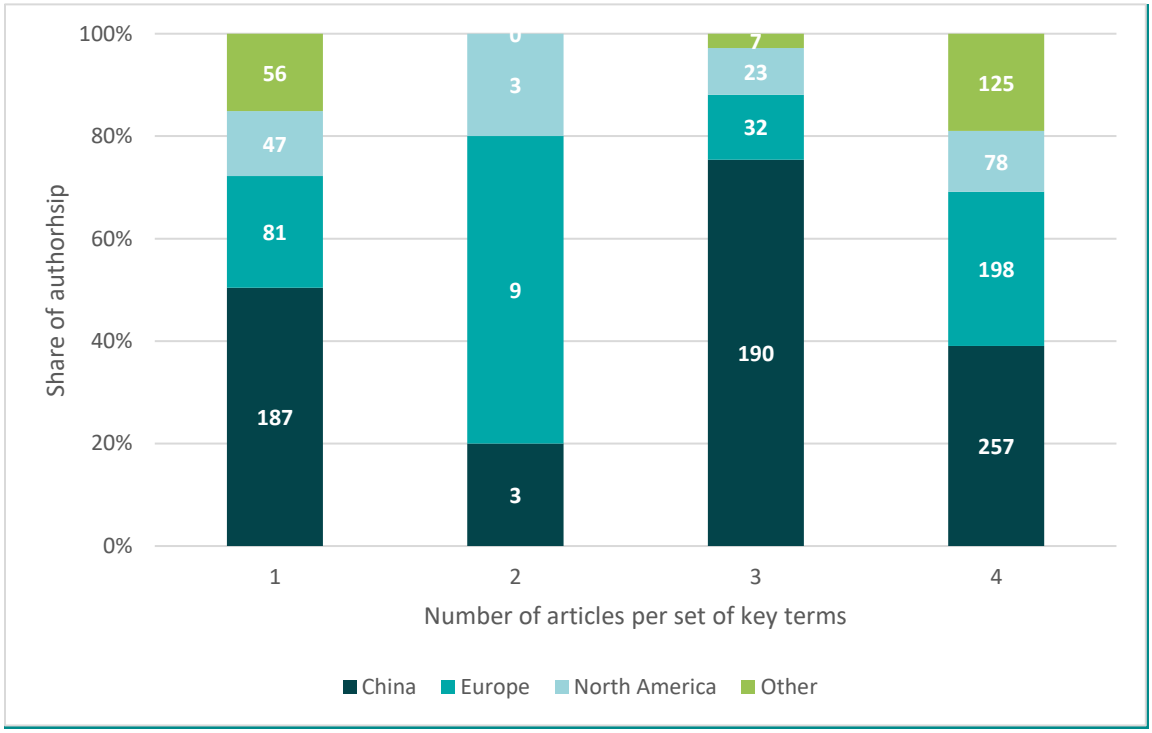

Figure 4-1. *Geographical representation of authorship per global region for the four sets of key terms.*

Note: The four sets of search terms: (1) Environmental carrying capacity, cities; (2) Earth carrying capacity, cities; (3) Ecological carrying capacity, cities; (4) Urban carrying capacity, cities; all in the time period 2010-2021 (see definitions of terms in Appendix A: Glossary)

4.1.2. Frameworks Used by Cities

Sustainability frameworks bring goals and actions together and provide a means for tracking progress (Sala et al., 2015). Our literature review on frameworks demonstrated that out of the 33 sustainability frameworks identified, 21 provided full coverage on all five domains of consumption established for the search criteria (food, buildings, consumables and wastes, transportation, and water) (as indicated by the green and orange arrows in Figure 4-2). Another four provided partial coverage, meaning fewer than all five domains of consumption were addressed. The remaining seven frameworks did not provide sufficient information about this topic to determine coverage. The frameworks aligned with ECC had, in some way, people living within the regenerative and assimilative capacities of nature as an explicit goal. Only 11

frameworks were fully aligned with this goal (those indicated with blue arrows in Figure 4-2), while 19 were partially aligned, meaning there were elements that address the goal but it was not identified explicitly as a goal unto itself or its treatment was partial or insufficient to fully achieve it.

A total of 11 sustainability frameworks covered both the goals of living within Earth's carrying capacity and also covered the five domains of urban consumption. For more details on which frameworks address all domains of consumption and which align with the goal of living within ECC, see Table B-1 in Appendix B. Lastly, 20 out of the 33 frameworks were developed in North America or Europe and 21 out of 33 frameworks were developed by a not-for-profit organization or a global organization such as the United Nations, C40, or the European Union. Urban metabolism (also known as material and energy flow analysis, or MFA), which allows an account and visualization of most materials and energy fluxes within a city. More often cities measure greenhouse gas (GHG) emissions, water, or waste flows. Most full MFAs available have so far been done by researchers (as snapshot studies, not longitudinal) and published in academic literature (Appendix D). As reported by knowledge holders (see section 4.3), some of the leading cities have started to do materials flow analysis with their own resources in circular economy endeavors. Our literature review also included two positive signs: urban metabolism analyses are gaining traction, largely in Asian cities, and European cities can now use the MFA methodology developed by Eurostat (although currently datasets are at the national level only). In North America, MFA is also starting to get more attention.

The frameworks from the Global Footprint Network (GFN), Living Cities Challenge, and Circular Economy concept are the only ones to align resource accounting and actions with the goal of living within ECC. GFN (which has adopted the ecological footprint) is used by 24 cities, followed by Living Cities Challenge in 13 cities and Circular Economy related frameworks in ten cities. Interestingly, most in our study participate in LEED Cities v4.1 framework (120 cities), ISO 37120 (100 cities), or C40 Climate Action Planning Framework (97 cities) which do not explicitly recognize the need to live within ECC. The C40 Thriving Cities Initiative acknowledges the need to live within planetary boundaries but is used by only three cities. Lastly, while 55 cities are engaged in the popular Resilience Cities Network, this does not incorporate the goal of living within ECC.

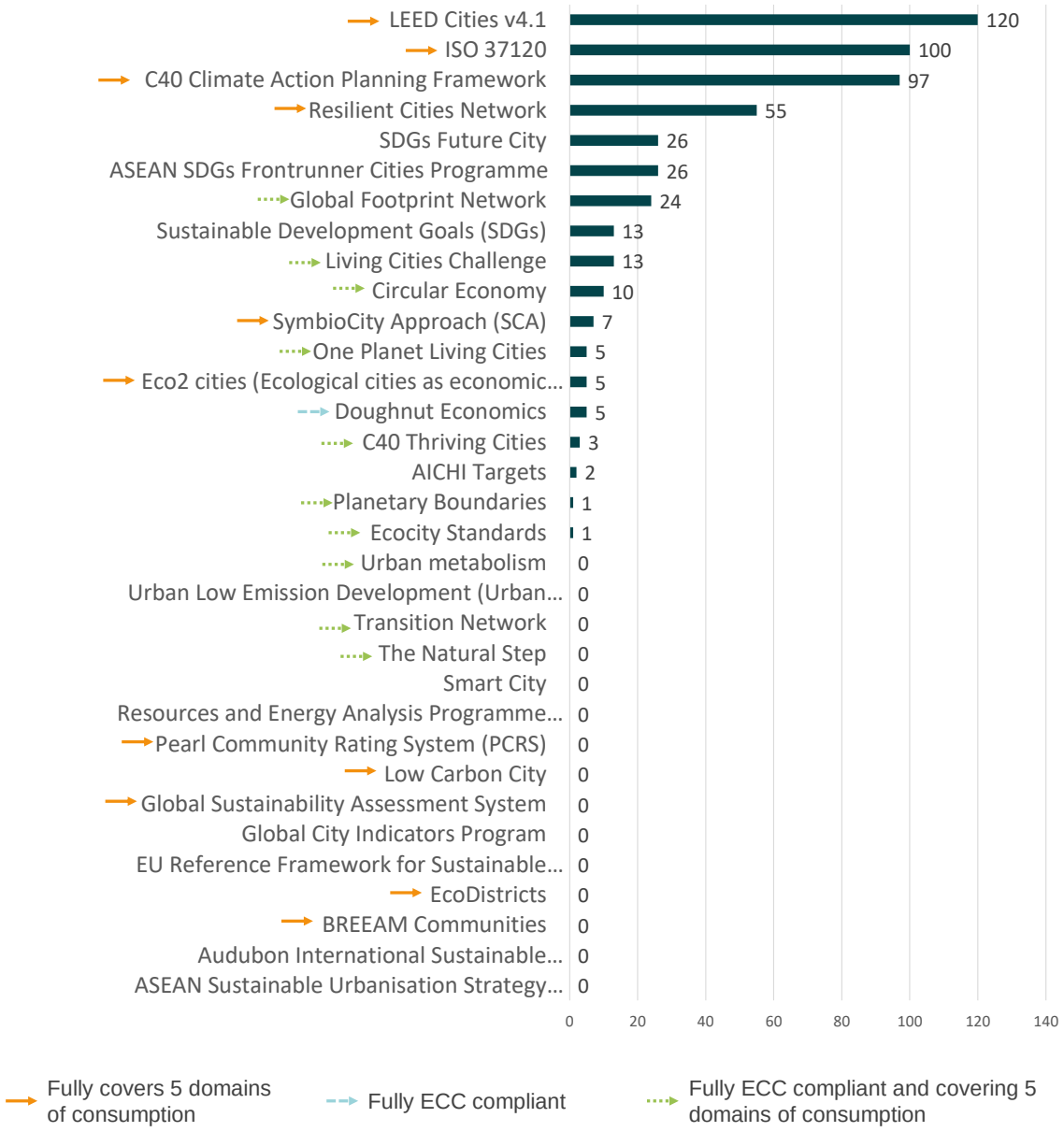

Figure 4-2. *Number of cities using sustainability frameworks covering five domains of consumption and/or being ECC compliant*

In researching the number of cities that engage in sustainability frameworks, it is clear that most are not aligned with the goal of living within Earth's carrying capacity. Moreover, for some of the fully aligned frameworks, there was no evidence from the literature surveyed that any cities were using them. Some possible reasons are that: cities using a newly developed framework or those that adopted one relatively recently are not yet captured in the literature; cities using fully aligned frameworks are being written about in languages other than English or French; cases of informal adoption of a framework may be bypassing detection because there is no formal registry or record of participation (e.g., International Ecocity Standards); some frameworks may be used by small cities or towns that are not being captured in the literature (e.g., BREEAM Communities and The Natural Step); and some frameworks may not be

suitable for use at the city scale (e.g., EcoDistricts, SymbioCity Approach, and Pearl Community Rating System).

Most frameworks, even popular ones such as LEED Cities v4.1, ISO 37120, Resilient Cities, or the UN Sustainable Development Goals (SDGs) do not empower cities to pursue living within ECC. While around two thirds of the sustainability frameworks identified cover all five domains of consumption, only a third include goals limiting resource demand (Williams & Millington, 2004) and support a transition to one-planet living. At the same time, many frameworks that align with the goal of living within ECC seem to not be adopted by city administrations and remain rather invisible, existing mainly in the academic or non-profit literature. It's likely that many city decision makers are not even aware of the nuances and the importance of the goal of living within ECC. Lastly, not all sustainability frameworks or tools promote a whole-systems approach or are followed by holistic implementation strategies, thus leading to lost opportunities and increased skepticism.

4.1.3. Methods, Tools and Metrics to Address Earth's Carrying Capacity

The following four accounting methods and tools used to measure living within ECC were identified:

- **Carbon Footprint Analysis (CFA)**: Measures the quantity of carbon (carbon dioxide and other gases with global warming potential in carbon dioxide equivalent) emitted directly or indirectly by a particular entity (Lombardi et al., 2017; World Resources Institute et al., 2014).
- **Ecological Footprint Analysis (EFA):** Accounts for the anthropic pressure a specific population exerts on its ecosystem and expresses it in terms of global hectares of productive land required to produce the resources needed to sustain the population and assimilates its wastes (Kissinger & Rees, 2010; Moore et al., 2013).
- **Material Footprint Analysis (MFA):** Accounts for the quantity of raw material extracted by a territory in a year and used either domestically or physically imported, and is generally measured in terms of Domestic Material Consumption (DMC) (Swilling et al., 2018). Another metric is the Total Material Consumption (TMC) that also considers the upstream impacts of resource consumption and can be separated in three main categories of material, namely abiotic, biotic and raw (Bringezu, 2015).
- **Water Footprint Analysis (WFA):** Accounts for the global amount of water used by a territory and considers three main categories being blue, green and grey water, related to the source of the flow considered, respectively groundwater and surface water, evapotranspiration from soil or assimilated with waste flows (Aldaya et al., 2012; Paterson et al., 2015).

The metrics were classified as climate based (greenhouse gas emissions, carbon), ecological footprint, and material flows analysis (see Table B-2 in Appendix B). Some units combine more than one dimension, such as carbon content in electricity: g CO_2/kWh; food emissions: GHG/CO_2 emissions/capita; emission factors in kg CO_2-eq./TJ. Material flows can include nutrients and other dimensions of the planetary boundaries (Rockström et al, 2009). To these methods and tools, Water Footprint Analysis (WFA) has been added as one of the primary metrics established in the literature to represent the general boundary conditions for living within ECC. Table 4-1 summarizes the connections between the methods mentioned, the indicators, and metrics, as well as their thresholds and main urban standards as identified in the literature.

Table 4-1. *Matrix showing the connections between primary methods, indicators, and metrics, and the related thresholds and urban standards.*

Methods	Material Flow Analysis (MFA)	Ecological Footprint Analysis (EFA)	Carbon Footprint Analysis (CFA)	Water Footprint Analysis (WFA)
Indicator	Material Footprint (Note 2)	Ecological Footprint (Note 3)	Carbon Footprint (Note 4)	Water Footprint (Note 5)
Metric	tonne/cap/year	gha/cap/year	tCO_2e/cap/year	m^3/cap/year
Sustainability threshold	DMC:6-8 $TMC_{Abiotic}$: 6 - 12 TMC_{Biotic}: 2 $TMC_{Raw\ material}$: 3 – 6 (Note 2)	Fair Earth-share: 1.6 (Note 3)	Carbon Budget: 3.4 (2030) 1.0 (2050) (Note 1) (Note 4)	Freshwater use: 363.6 (Note 5)
Main Urban Standard	○ Eurostat (Note 2)	○ Ecological Footprint Standard (Note 3)	○ GPC ○ PAS 2070 ○ Bilan Carbone ○ IPCC ○ US Community Protocol (Note 4)	○ Water Footprint Assessment Manual ○ ISO 14046:2014 ○ Eurostat (Note 5)

Notes: 1) In parenthesis, the year linked to the decreasing emission target. 2) Sources for MFA: (Bringezu, 2015; European Commission. Statistical Office of the European Union., 2018; Swilling et al., 2018). 3) Source for EFA: (Global Footprint Network, n.d.-a; Vigier et al., 2021). 4) Source for CFA: (Association Bilan Carbone (ABC), 2017; Chen et al., 2019; Institute for Global Environment Strategies et al., 2019; The British Standards Institution, 2014; Wilmsen & Gesing, 2016). 5) Sources for WFA: (Aldaya et al., 2012; Gleeson et al., 2019; ISO, 2014; Li et al., 2020; Vigier et al., 2021).

To assess sustainability at urban scale, CFA are the most used frameworks. Table 4-2 summarizes the common accounting boundaries used to delimit the CFA evaluation, according to the sources of emissions considered. They are conventionally referred to as “Scopes”, shown in Figure B-1 in Appendix B.

Table 4-2. *Accounting Scopes for impact assessment and their coverage.*

Scope 1	GHG emissions from sources located within the city boundary.
Scope 2	GHG emissions resulting indirectly from the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	GHG emissions resulting from activities occurring outside the city’s boundaries which are induced by activities within the city boundary. It includes emissions from supply chains either linked to delocalized production or consumption by the city’s inhabitants and industries. Scope 3 is often a significant part of high-consuming cities’ total GHG emissions.

Scope 1 and Scope 2 therefore describe the impacts resulting from activities occurring within a city’s boundaries and encompass the emissions considered in a production based approach, whereas Scope 3 encompasses the city’s impact on its surroundings and is therefore necessary for consumption based analysis. For cities located in developed countries, a consumption based approach typically results in a higher reported impact than the production based approach, which makes its assessment a crucial step for evaluating cities’ impact in their entirety (C40 Cities, 2017; Moran et al., 2018; Wiedmann et al., 2020). Table 4-3 defines the main CFA standards for accounting and their compliance to a consumption-based approach.

Table 4-3. *The various carbon footprint accounting standards and protocols.*

Accounting framework		Details and organization	Consumption based standpoint
GPC	BASIC	The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) is used worldwide and was developed in 2014 by the World Resources Institute, C40, and ICLEI (Arioli et al., 2020). The BASIC level measures GHG emissions attributable to activities occurring within the geographic limits of the city and considers stationary energy and in-boundary transportation (Scopes 1 and 2) and some part of the in-boundary generated waste (Scopes 1 and 3).	
	BASIC +	The BASIC+ level reports the same emissions sources as BASIC but with more details and involves additional sources such as Agriculture, Forestry and Other Land Use (AFOLU) and Industrial Processes and Products Use (IPPU). Scope 3 emissions are included for some sources and additional ones can be added at the discretion of the city.	✓ But incomplete for not all Scope 3 emissions are required
LGOP		The Local Government Operations Protocol (LGOP) was designed in 2010 by California Air Resources, ICLEI and the Climate Registry (California Air Resources Board et al., 2010), it assesses emissions linked to metro regions' operations: direct emissions from its equipment and facilities (Scope1), emissions from the energy grid (Scope 2), and those linked to metro region activities and occurring outside its boundaries (Scope 3).	
NCOS		The National Carbon Offset Standard (NCOS) has been tailored to Australian context and provides organizations with recommendations and guidelines to report their emissions with a goal of carbon neutrality (Commonwealth of Australia, 2017). At the urban scale, it considers organizational boundaries and the direct and indirect emissions linked to the city's operations, omitting the households' one.	
ALas		The Alueellinen Laskenta (ALas), regional calculation model has been developed by the Finnish Environment Institute (SYKE) to measure the GHG emissions of Finnish municipalities (Finnish Environment Institute (SYKE), 2021). The calculation method is usage-based and resemble the BASIC level of GPC Standard.	
LEGGI		Created by the Greater London Authority (GLA), the London Energy and Greenhouse Gas Inventory consider emissions from the energy grid (Scope 2), direct emissions from IPPU, AFOLU and waste (Scope 1), and other selected emissions induced by city activities despite occurring outside the city's boundaries (Scope 3)(Greater London Authority, n.d.).	✓ Scope 3 mentioned, although not reported in practice
Bilan Carbone		Developed in France by the environmental organization ADEME (Association Bilan Carbone (ABC, 2017), it accounts for emissions occurring within the city's boundaries and linked to the energy sector (Scopes 1 and 2) and for all emissions by the city's inhabitant's lifestyle regardless of their location (Scope 3).	✓ Yes, all Scope 3 emissions are mandatory to report
LAK		LänderArbeitskreis Energiebilanzen (LAK) methodology, developed by the homonym organism is mainly used in Germany and accounts for both a sectorial-based approach (Quellenbilanz) and a consumption-based one (Verursacherbilanz) (Länderarbeitskreis Energiebilanzen, n.d.-a). The latter works on a "polluter-pays" principle and emissions are attributed to the consumer, regardless of physical source.	✓ Yes, under the Verursacherbilanz

The important observations from Table 4-3 are the following:

- The **GPC BASIC, LGOP**, **NCOS** and **Alas** frameworks cannot be used to report consumption-based emission for a city because they are either too narrow regarding the sources comprised in Scope 3 evaluation (i.e. only sources related to the waste sector are reported, out of boundary travels are not reported) or they are limited to the metro area's operations, thus not considering the whole city by omitting the household's consumption and out-of-boundary travel which are essential for a comprehensive consumption-based approach (California Air Resources Board et al., 2010).

- **GPC BASIC +** only requires the reporting from transboundary transport, energy and waste sources (World Resources Institute et al., 2014). Hence, by overlooking other important categories of Scope 3 emissions (namely goods, food, construction and water), evaluated to account for about half of global Scope 3 emissions, GPC BASIC + framework lacks completeness to rigorously assess a city's impact with a consumption-based approach (Chen et al., 2019; Wiedmann et al., 2020).
- **LEGGI** could in theory reflect on a city's indirect emissions impacts, although in practice, a lack of requirements in Scope 3 reporting makes the framework mainly about Scope 1 and Scope 2 (The British Standards Institution, 2014).
- **LänderArbeitskreis Energiebilanzen** (Verursacherbilanz) encompasses all embodied emissions linked to circulation, services and household consumption and construction (Länderarbeitskreis Energiebilanzen, n.d.-a, n.d.-b; Stein, 2018). Some sectors such as waste or water do not seem to be lacking evaluation, although because of a language barrier (most documentation of this framework is in German), it is rather difficult to conclude on the completeness of the framework.
- **Bilan Carbone** seems to be able to transcribe consumption-based emissions for a given city in a more comprehensive manner (Mirabella & Allacker, 2021). It relies on life cycle analysis, accounts for all embodied emissions linked to a city's activities, and has a specific consumption-based methodology framework.

4.2. Theme 2 – Governance and Policy Implementation

4.2.1. Governance

For the first step (the exploratory literature search), we identified the most common models of governance in the literature (listed from most to least frequently used): Urban Governance, Good Governance, Transformative Governance, Smart City Governance and Participatory Governance, Climate Governance, Sustainable Governance, Transition Management/Transition Governance, Earth System Governance, and Anticipatory Governance (see definitions in Appendix A: Glossary). Key words such as "planetary boundaries", "sustainable cities", and "lifestyles" were more common in the literature than "one planet living", "one planet cities" and "living within Earth's carrying capacity". The literature reviewed is predominantly from authors located in Europe, followed by those in Asia, North America, Oceania, Africa, and South America; whereas cities studied in this body of literature were primarily in Asia and Europe, followed by North America, Africa, Oceania and South America.

After shortlisting 21 cities as achieving absolute reductions (Theme 1), we attempted to connect these cities with governance models that they report using or with governance models that are associated with the city in peer-reviewed literature. The review of academic and grey literature (including municipal websites) revealed governance models correlated with these cities but the connection was predominantly implicit. Cities did not explicitly state which governance model they were working with and if a governance model was mentioned there were limited details on how it was contributing to achieving absolute reductions. If no governance model was mentioned, we looked for descriptions of sustainability operations and methods that seemed aligned with such models. Through these approaches, we found that 15 cities referred to working with Good Governance, 8 cities to working with Urban Governance, and 6 cities to working with Smart (e-)Governance. The remaining models were mentioned by only one of the

shortlisted cities. Figure B-6 in Appendix B provides a visual of the governance models identified in the 21 cities and those used more frequently.

4.2.2. Sub-Theme: Leadership by Cities and Communities Achieving Absolute Reductions

Several challenges stand in the way of the identification of leading cities towards ECC (Vigier et al., 2021). Among them is the lack of a comprehensive international urban database for sustainability indicators other than the carbon footprint (such as ecological, material or water footprint). As a result, our selection of cities is mainly based on carbon footprint reduction. Based on the methodology explained in 3.2.3, the preliminary identification of cities reducing their carbon footprint were identified and are presented in Figure 4-3. This map shows that leading cities are located primarily in North America and Europe, however, poor access to quantitative data in low-consuming cities from Global South biases this identification.

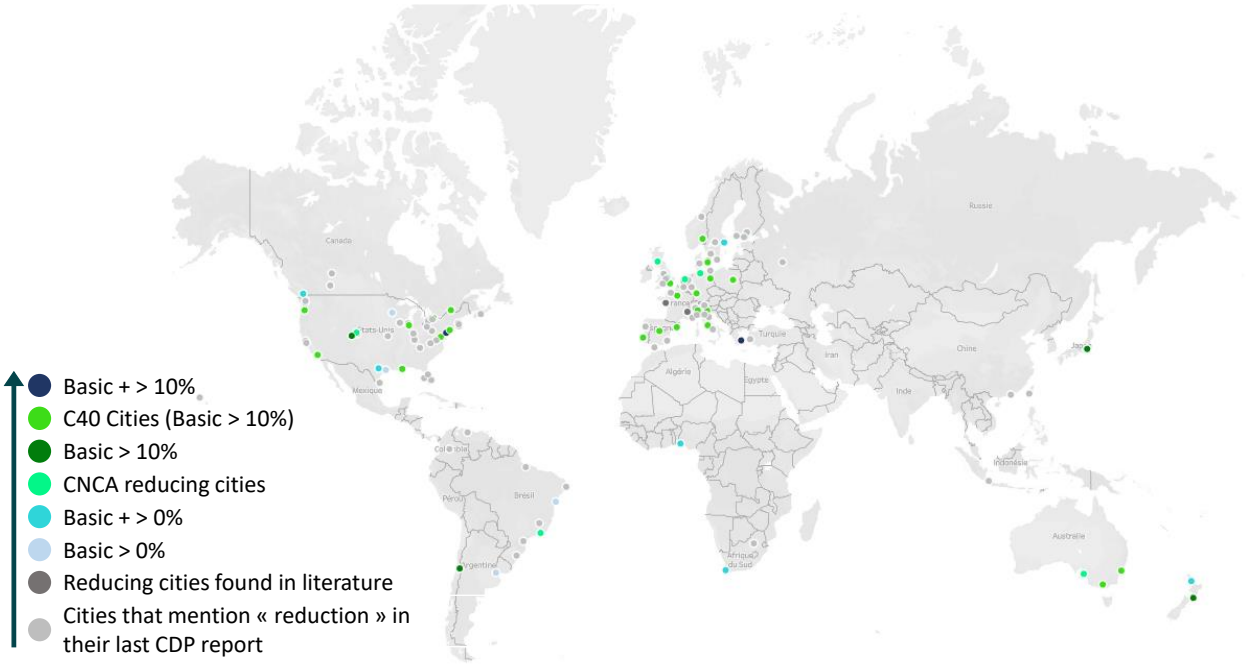

Figure 4-3. *Cities reducing their Carbon Footprint in ascending order of involvement (Sources: CDP Databases, C40 databases, CNCA's website, cities' own databases).*

Among the 136 cities identified, not all of them were reporting their carbon footprint with the same completeness (BASIC or BASIC +), for greater precision increases the complexity and data intensity of the assessments. The main difference between the methodologies resides in the extent to which indirect emissions are considered (see Table 4-3). When specifically analyzing Scope 3 emissions, few are the cities reporting these indirect emissions (see Figure B-2 in Appendix B). Among these cities, only eight were found reducing their indirect emissions between 2018 and 2019 and merely four with a decrease superior to 10 %. Because most of the cities identified in Figure 4-3 are located in high-consuming areas with important Scope 3 emissions, a wider report of Scope 3 emissions would be needed to rightfully measure their global carbon footprint.

To shortlist the cities further, additional criteria were considered such as membership in, or use of a framework of, an international sustainable city network. To emphasize intentionality, data were retrieved

from cities that began their emission reductions before the timeframe of this study (2010-2020), to further reflect on their overall reduction in environmental impact. This made comparison across databases and accounting methods difficult. Cities with an overall emission reduction greater than 15% since their earliest available data were then shortlisted, as shown in Table 4-4.

Following the carbon footprint-based analysis, a thorough search for EFA performed at the city scale was carried out as an attempt to review cases where sustainability impacts were evaluated in a more holistic way beyond a limited evaluation of GHG emissions. This research demonstrated that assessing recent urban environmental impact variations through EFA was a difficult task, as longitudinal studies using data from after 2010 were lacking (see Table 4-5). Moreover, most of the cities for which data were found are located either in Canada or in the Mediterranean region (see Table B-4 in Appendix B). Although these cities evidently record their footprint, we cannot definitely deduce that they are the cities with the most reductions in the world because of the absence of adequate longitudinal data. Indeed, except for Tokyo and Xiamen, all the other selected cities were identified thanks to two academic papers comparing several cities either in Canada or around the Mediterranean area (Baabou et al., 2017; Isman et al., 2018). As a result, leading cities' identification is constrained by the accessibility of longitudinal studies (preferably performed by the same authors).

Table 4-4. *Shortlisted cities and their respective carbon footprint (CF) reduction.*

Cities' GHG emissions reduction in %		Years		Accounting method
Copenhagen	54%	2005	2019	Scope 1 and 2
Lahti	49%	1990	2019	ALas model
Portland, OR	41%	2006	2018	The Local Government Operations Protocol
San Francisco	41%	1990	2019	GPC - Basic
Glasgow	37%	2005	2017	Scope 1
Stockholm	37%	1990	2015	Scope 1
Toronto	37%	1990	2018	GPC - Basic
Washington, DC	32%	2006	2019	GPC - Basic
Melbourne	31%	2011	2018	National Carbon Offset Standard
London	29%	1990	2018	LEGGI
Helsinki	27%	1990	2017	Scope 1 and 2
Vancouver	25%	1990	2019	GPC - Basic
Boulder	21%	2005	2019	GPC - Basic
Hamburg	21%	1990	2017	LänderArbeitskreis Energiebilanzen methodology
Paris	20%	2004	2018	Bilan Carbone
Minneapolis	19%	2006	2019	Scope 1 and 2
Lakewood	18%	2007	2018	GPC - Basic
Sydney	17%	2005	2015	GPC - Basic
Chicago	15%	2005	2017	GPC - Basic
Adelaide	15%	2006	2018	GPC - Basic
New York City	15%	2005	2019	GPC - Basic

Note: sourced from the cities' own websites.

Table 4-5. *Ecological Footprint Assessments (EFA) reviewed through bottom-up literature research.*

Cities or regions with at least 1 EFA *(1990 -2020)*	Cities with at least 1 EFA *(1990 - 2020)*	Cities with at least 1 EFA *(2010 - 2020)*	Cities with longitudinal EFA *(1990 – 2020)*	Cities with longitudinal EFA *(2010 - 2020)*
325 (100 %)	235 (72 %)	93 (28 %)	81 (24 %)	37 (11 %)

Note: The dates in parenthesis refer to the period in which the assessments were performed – as opposed to the years of publication of the assessment themselves

Among the selected cities, the variation of their ecological footprint over the years was both calculated on an absolute and on a per capita basis (see Table B-2 in Appendix B). Often, the ecological footprint is calculated on a normalized basis to be compared to the *fair earth share*, being the equal share of global biocapacity shared between all Earth inhabitants. However, by only monitoring per capita variation, the impact of the population is overlooked, and misrepresentation can be induced. Hence, when absolute ecological footprint for a specific city was not explicitly given in the assessment, demographic data of the corresponding year were retrieved from the database *World Population Review* to evaluate it (World Population Review, n.d.). Discrepancies may have resulted from this use of different sources to describe urban demographics. It was then discovered that out of 25 cities reducing their per capita footprint, almost half of them were in fact increasing their overall impact because of population growth. This observation highlights the importance to consider anthropic factors when assessing a city's impact in its entirety.

4.2.3. Identifying Key Urban Policies in Shortlisted Cities

Once a shortlist of cities exhibiting emissions reductions was identified, the goal of the urban policies research was to develop an understanding of the current state of policymaking amongst them. This research highlighted the fact that urban policies can be divided into two major categories: a common baseline set of policies adopted by all, and a collection of rarer, more ambitious initiatives whose implementation depends on the local governance context.

To maintain the focus of this report, the research was limited to collecting information about shortlist cities, rather than global trends in policymaking. An overview of this research is presented in Tables 4-6 and 4-7. Approximately half of the research was conducted using general overview sources from the grey or academic literature, which either compile case studies across large numbers of cities, cover general trends, or provide comparisons between cities or regions. Although they do not explicitly highlight the shortlisted cities, these overview sources allowed for information on urban policies to be collected in a consistent manner and provided a baseline of knowledge on the current state of urban policymaking.

The remainder of the research was derived from the city profiles, where individual grey literature resources relating specifically to each city were catalogued. This literature complements the existing case study compilations, which were intrinsically limited in their scopes due to the sheer number of permutations of cities and policies. The use of grey rather than academic, city-specific literature was necessary due to the diversity of sources covering the actions of individual cities, and the inability of the academic literature to deliver a clear image of contemporary policy developments across such a large number of cities. Several non-shortlisted cities, mostly from the Global South, were also researched to provide context and information on alternative pathways.

Table 4-6. *Overview of Grey and Academic resources.*

Each source is outlined in the Annotated Bibliography in the Appendices.

Overview Grey Resources – Compilations of policy case studies
• Transport Innovations from the Global South - Case Studies, Insights, Recommendations • C40 Cities Case Studies • UREx Sustainability Research Network Case Studies • Green Building City Market Briefs • Parking and Travel Demand Management Policies in Latin America • Urban Biodiversity Hub Map of Policies and Initiatives • Urban Access Regulations Website
Overview Academic Resources – Global trends in policy design, and regional comparative analyses
• Urban Planning Models and Model Cities • Literature review on good practices to improve the recycling performance of urban areas • Comparative analysis of solid waste management in 20 cities • Policy design for sustainable urban transport in the Global South • Urban Planning in the Global South • Carbon Dioxide Emissions and Economic Growth • Fossil CO_2 emissions in the post-COVID-19 era • Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany • Benchmarking performance of solid waste management and recycling systems in East Africa

Table 4-7. *Additional grey literature compiled for each city, organized by topic.*

Shortlist Cities				
Cities (Key policies)	General	Transport	Buildings	Waste, Water, Consumables
Vancouver (Transit Oriented Development)	• Greenest City Action Plan 2015 • Green Grants • Renewable City Strategy 2015	• 2016 Ten Year Vision	• Zero Emissions Building Plan 2016 • Energy resources and programs for existing buildings • Vancouver's district energy market	• Coquitlam Landfill Gas Collection System • 2011 Solid Waste Management Plan and 2019 report
Portland	• 2015 Climate Action Plan	• 2020 Transportation System Plan	• 2020 Low-Density zoning reform • 2020 Home Energy Score Ordinance	
San Francisco (Recycling, Parking Policy)	• Plan Bay Area 2040	• 2017 TDM Plan • BART Silicon Valley Extension • SF Park • 2018 Electrical Vehicle Roadmap	• 2020 Environmental Code and 2008 Green Building Ordinance • Existing Buildings Energy Ordinance • 2018 SFO Carbon Neutral Strategy • City-Owned Solar system	• 2009 Mandatory Recycling Ordinance • Zero Waste Programs
Toronto	• Transform TO 2017 • Toronto Atmospheric Fund	• Transit Expansion Projects • 2041 Regional Transportation Plan	• Eco-Roof Incentive Program • Sustainable Neighborhood Action Program • 2009 Green Roof Bylaw • Green Building Standard	• 2016 Long Term Waste Management Strategy
New York City (Transit)	• 2019 Climate Mobilization Act • Mayor's Office for Sustainability Programs	• 14th Street Busway • Cleaner Trucks for a Greener NYC • Ped. Improvement Projects • NYC Congestion Pricing Plan	• Green Housing Preservation • Greater, Greener Buildings Plan • City Capital Green Building Program	• Zero Waste Goal • NYC Watershed Protection Program
Chicago	• 2008 Chicago Climate Action Plan		• Retrofit Chicago	• Blue Cart Recycling Program
Washington DC	• Clean Energy DC • Climate Ready DC • Sustainable DC 2.0 Plan		• Smart Roof Program • Green Buildings	
London (Transit, Congestion Charge)	• The London Plan 2021 • London: Planning the Ungovernable City	• London Congestion charge and pollution reduction • Urban Access Regulations • London Cycleways	• RE:FIT • Guidance on sustainable design and construction	

Paris (Transit, Cycling, Pedestrian space)	• Plan Climat Air Energie	• Paris as cycling success story • e-Bike incentives • ZCR environmental zone • Urban Access Regulations: Paris • Deployment of Low Emission Zones • Velib Bikeshare		
Stockholm (Congestion Charge)	• Climate Action Plan 2020-2023	• Stockholm Congestion Pricing		
Copenhagen (Cycling)	• CPH 2025 Climate Plan • Copenhagen Climate Projects	• Low emission zones in Denmark		
Amsterdam (Cycling)	• Sustainability and energy policy	• Policy: Traffic and Transport		
Glasgow	• Climate Emergency Implementation Plan	• Glasgow Low Emission Zone		
Oslo (EV Incentives)	• Climate Strategy for Oslo towards 2030 • Climate and Energy Strategy	• Olso electric vehicle capital		
Belo Horizonte (BRT)	• Plano Diretor Belo Horizonte			• Integrated solid waste management

Note: Empty boxes mean that sufficient information on the specific policy area in question was obtained from the overview case study compilation sources. A summary of the literature compiled on non-shortlisted cities can be found in the Annotated Bibliography in the Appendices.

The large number of sources compiled for individual cities allows for trends in policymaking to be identified. Table 4-8 summarizes the research outlined in the previous two tables and separates urban policies into two major groups: universally adopted policies, and less common policies. The first category includes Green Building Codes, investments in transit (though there is significant variation in extent), the existence of recycling programs, and financial incentives to reduce energy and water consumption, or waste production. The second group includes restrictions on cars such as congestion pricing schemes, bans on single-use plastics, and district heating systems. The distinction between these two groups and its implications on future policymaking is expanded upon in the synthesis section of this report.

Table 4-8. *A summary of the policies adopted in key cities featured in this report.*

		Green Building Requirements	Transportation investments	Recycling programs	Demand-side incentives *	Significant restrictions on cars **	Outright Bans on single-use plastics	Green roof requirements	Urban growth boundaries	Citywide densification policies	District Heating systems	Significant bicycle network
		Group 1				Group 2						
Shortlisted Cities	Portland		X	X	X				X	X		
	Vancouver	X	X	X	X				X		X	
	San Francisco	X	X	X	X		X	X				
	New York City	X	X	X	X					X	X	
	Washington DC	X	X	X	X							
	Toronto	X	X	X	X			X	X			
	Sydney	X	X	X	X							
	Melbourne	X	X	X	X							
	London	X	X	X	X	X			X			
	Paris	X	X	X	X	X	X			X	X	X
	Stockholm	X	X	X	X	X			X		X	
	Copenhagen	X	X	X	X			X	X		X	X
Non-Shortlisted ...	Amsterdam	X	X	X	X					X		X
	Singapore	X	X	X	X	X		X				
	Barcelona	X	X	X	X	X		X				
	Zurich	X	X	X	X							
	Tokyo	X	X	X	X	X				X		
	Milan	X	X	X	X	X			X			
	Freiburg	X	X	X	X						X	X

***inc. metering, retrofits**

****inc. congestion charges, tolls, widespread pedestrianization of spaces**

4.2.4. Sub-Theme: Alternative Knowledge Systems and Development Pathways

The literature review demonstrated the need to challenge the business-as-usual view of humans as living apart from ecosystems and to embrace alternative approaches to development that require turning to urban ecology theory which sees cities and urban dwellers as part of ecosystems. A way to challenge the dominant development paradigm is through a shift from the current resource-extracting and individualistic model of business-as-usual (reducing the impact) to a positive, systemic model of a city that regenerates nature and reduces its ecological and material footprint (Spiliotopoulou, 2021). Such shift can be achieved with investment in alternative pathways that add nature's intrinsic value and biodiversity's right to exist in urban sustainability practice (Lieber, 2018).

The decades-long weak/strong sustainability debate, which emerged in economics but is now central to sustainability discourse, is a spectrum between increasing resource supply with technology (weak) and limiting resource demand (strong) (Williams & Millington, 2004). The belief systems of the current urban

development paradigm are informed by weak sustainability and promote an anthropocentric worldview that perpetuates unsustainability. They assume indefinite economic growth with technological efficiencies and innovation compensating for the ecological damage and natural resource depletion (Dernbach & Cheever, 2015). However, Earth is a complex closed system and thermodynamics pose limits to growth; exceeding the limits and depleting resources faster than they regenerate will lead to collapse (Tainter & Taylor, 2014).

Alternative development pathways are guided by *strong sustainability* principles, i.e., the belief that ecosystem services are essential, not monetizable, and not substitutable by human-made capital such as technology. They are also grounded in the *ecological worldview* upheld by Indigenous (and some non-Indigenous) communities around the world (Du Plessis & Brandon, 2015). The ecological worldview, in contrast to the western, mechanistic paradigm, can help societies live within ECC through the (re)connection with *Mother Earth* and co-evolutionary development processes. It emphasizes planning for at least seven generations ahead (or about 140 years into the future), harvesting ecosystem services (critical natural capital) at a rate lower than that of their regeneration, and minimizing the extraction of non-renewable resources (Du Plessis & Brandon, 2015; Mang & Reed, 2019). Indigenous viewpoints specifically consider human beings as long-term visitors to the land, not settlers or superior to other living beings (Wahl, 2016).

The reality of ecological overshoot requires reduction of our demand on resources and one pathway to achieve this is by *ascribing value to ecosystem services*. In questioning the commodification of local and regional land that offers precious ecological services, cities should include values of ecosystem services in their financial accounts and in their trade-offs with competing land uses such as real estate development. Municipalities such as Gibsons and West Vancouver in British Columbia already account for the value of such productive lands and the Municipal Natural Assets Initiative (MNAI) has been piloting an approach to embed natural assets into municipal accounting with cohorts of municipalities across Canada (MNAI, n.d.,)(MNAI, 2020).

Another alternative pathway can be traced to the approaches of *bioregionalism, self-reliance* (largely western notions), *and self-determination* (largely an Indigenous notion) which emphasize the connection of communities to their local ecosystem services and flows, in contrast to politically defined – but not aligned with nature – boundaries of the dominant paradigm. Bioregionalism stresses that the biological features of the local or regional system determine the level of human population that a specific land can sustain (Wahl, 2016). Related initiatives encourage local diversification and social equity and typically acknowledge the limits to local community capital and that the road to self-reliance requires collective agreement, capacity-building, and collaborative and holistic decision-making (Curtis, 2003; Wahl, 2016).

Regenerative development, agriculture, and design are complementary alternative pathways toward living within ECC. Restoring and enhancing urban ecological processes, planned with contextual and systemic thinking and based on traditional Indigenous knowledge, can offer net-positive socio-ecological value, contribute to increased local resilience, and strengthen the cities' bioregions (Beatley & Newman, 2013; Condon, 2020; Wahl, 2016). *Regenerative, net-positive, and biophilic design* are also grounded in living systems theory and strive for optimization of benefits for people and nature (Cole, 2015; Mang & Reed, 2019).

Regenerative design, in specific, has been extensively implemented in agriculture with outcomes that are ecologically sustainable, resource-productive, and profitable (LaCanne & Lundgren, 2018; Rodale

Institute, 2014). Practices of *regenerative farming or holistic agriculture* include: biodynamic farming; permaculture; agroforestry; Natural Systems Agriculture projects; and energy efficient and hydroponic use of farmland (LaCanne & Lundgren, 2018). While the alternative pathways of permaculture and agroforestry offer multiple long-term benefits such as soil conservation and ecological resilience, they cannot sustain the current human population. They will additionally require a transformation in belief systems that incorporates the Indigenous ecological worldview, other alternative approaches, and an extensive protection of ecosystem services (on at least 30-50% of global lands, compared to ~16% protected today) (Green Dreamer, n.d.; Jones, 2021; Marris, 2019; Ward et al., 2020).

Inextricably linked to the alternative pathway of ecological and resource regeneration, *social equity and equitable distribution* of costs and benefits are essential elements of an urban transformation toward operating within ECC. As the "doughnut economics" framework urges, communities must address social boundaries (basic needs as the inner circle) along with global ecosystem boundaries (outer circle) to ensure achievement of both human and ecological health (Raworth, 2017). Wealth redistribution, human-nature equity, and Indigenous justice and reconciliation are necessary conditions for a socially just transition (Waridel, 2019). At the same time, developed nations must reinvigorate local production of good on their territory to reduce "modern slavery" in the Global South (Bihouix, 2019). With new economic pathways cities and countries can continue reducing the carbon embedded in the GDP and increasing the value-added per unit of primary energy.

Building *social capacity for a just urban transformation* entails continuous and robust involvement of all urban actors and overall development of the human, intellectual, socio-cultural, and political community assets (MacDonald et al., 2018; Wolfram, 2016). Regenerative sustainability, a more recent concept built on constructivist social theory, emphasizes collaborative planning, holistic and living-systems design, and participatory backcasting to ensure that all perspectives are considered, including nature's intrinsic value (De Jong et al., 2015; Robinson & Cole, 2015). While participatory governance has emerged as a western, Global North approach, the Indigenous viewpoint of *horizontal governance* and sharing of values is paramount in urban decision-making toward living within ECC.

The above alternative pathways have something in common: they all pursue meaningful involvement of citizens and adopt a whole-systems perspective (everything is connected to everything else) in co-creating healthy and inclusive urban space that benefits all living beings. They therefore align both with the goal of living within Earth's capacity and the five domains of consumption. To achieve such "regenerative cultures", we must embrace and apply transdisciplinarity and question the dominant development paradigm and mainstream assumptions on priorities, needs, and values (Wahl, 2016). Cities should adopt the ecological worldview of Indigenous people and follow a shrink-share-regenerate approach to reduce demand on resources while ensuring equitable sharing of benefits (Kitzes et al., 2008; Rees, 2020).

Our research identified an abundance of initiatives worldwide that demonstrate the above alternative pathways in practice, albeit not in one single city or community. Many are context-specific projects developed and implemented locally, whereas others are practices adopted in broader sectors. Some initiatives belong to both categories: following sectoral approaches while being locally developed (Spiliotopoulou, 2021). It is worth noting that there is a strong representation of Global South cities that implement such holistic initiatives despite being lower consumers of energy and materials than most Global North cities (Kennedy et al., 2015); some examples are Viña del Mar (Chile), Kigali (Rwanda), and Medellín (Colombia).

Changes must happen from the individual choices to the global level. At the individual level, people can make a difference in their choice of consumption, means of transportation, eating and waste sorting habits (Barrau, 2019). At the community level, repair cafés, second-hand stores, and social activities are examples of reuse; these promote zero waste and reduce the consumption of primary resources (Bihouix, 2019). More engaging research is needed on how to regenerate natural assets. The constant ecological degradation is a disaster we are inflicting upon our land and ourselves and solutions must consider 26 dimensions (politic, economic, ethics, symbolic, psychological, demographic, mythologic, philosophic, poetic, semiotic, technic, axiological, taxonomic, sociological, alethic, energetic, mediatic, scientific, artistic, statistics, ontological, praxeological, semantic, critics, metaphysics, geographic) to fully resolve the issues (Barrau, 2019).

4.3. Knowledge Holder Interviews

The interviews with knowledge holders of the leading cities achieving absolute reduction in the 2010-2020 timeframe have revealed several key trends: Firstly, many cities have adopted frameworks informed by Circular Economy concepts (for material flows), the Paris Agreement (GWP mitigation), and the Sustainable Development Goals (SDGs) (Table 4-9). The SDGs are embedded in the city organization when it is a framework chosen by cities. The fact that the Paris Agreement and SDGs were not intended for cities makes the popularity of the SDGs even more striking, though their adoption is by no means universal, receiving critiques from one of the city stakeholders interviewed. Secondly, carbon neutrality is a near-universal goal, with 2050 being the most common target date. Thirdly, all cities also saw the adoption of internal climate plans as a crucial step towards creating a more (if not complete) unified sustainability vision for the city. These plans are often informed by external frameworks, but usually supersede these to become the new touchpoint for the city. A focus on public input, through public committees, round tables, master plans, participatory budgeting and online consultation platforms, was universally acknowledged as the key to the creation of the new internal frameworks.

A challenge is the low number of cities that have implemented consumption-based emissions accounting, which includes Scope 3 emissions accounting. There is variation even within the Scope 3 cities studied, with only Paris including emissions from food and air travel in their consumption-based accounting. Despite their leading position, Paris's leaders are supportive of a diversity of consumption-based accounting approaches being used.

This variation was reinforced in other city interviews. Cities have different geographical scopes, ranging from a large metro area to a relatively small settlement, and have different levels of authority over specific policy areas. These varying scopes and levels of authority significantly affect which policy areas cities can influence directly and which are either out of reach or require collaboration with regional or national governments. Table 4-9 highlights these areas of limited authority, and Table 4-10 outlines the city relationships to senior government and areas of tension and resolution. Additionally, many cities highlighted the importance of youth education programs to affect behavior-change among the next generation.

Cities have different government structure, leading to differing levels of institutional inertia. Those with a relatively centralized structure and a unified vision for sustainability tended to express an explicit desire to assume climate leadership roles (beyond the aspirations for recognition found in all cities interviewed) and include Belo Horizonte, Copenhagen, Helsinki, Paris, San Francisco, and Stockholm. Belo Horizonte specifically expressed a level of urgency concerning climate mitigation measures far beyond the other

cities interviewed, a direct result of the existential threat posed by floods and landslides, of which there is little equivalent in the other cities. Cities with a "weak-mayor" system of government in which the city council solely holds authority, such as in Portland and Lakewood, reported having a more difficult time adopting transformational policies, and may also have more difficulty adopting a cohesive, government-wide vision for sustainability. These cities are more reactive than proactive, and focus on doing what they can, where they can, given the resources available to their environmental department.

Finally, cities exhibit a wide variety of relationships to their regional, state, or national governments. Cities like Paris, Helsinki or San Francisco have relatively good relationships with senior levels of government (France, Finland, California, respectively), as a result of aligned values and incentives, whereas others, such as Portland, experience tensions with regional or state government due to differing sets of values. The City of Tokyo submits request of proposals every year in response to federal policies and budgets. The quality of a relationship may vary by policy area: for example, San Francisco has good regional relationships with regard to expertise sharing, but experiences tensions on housing policy as a result of the regional housing crisis. Many cities expressed concern about being pre-empted by senior levels of government which may prevent a city from implementing its own policy agenda, as was the case with Copenhagen, even if the senior government is broadly aligned with city values. Politically rightward swings at the national level can have a significant chilling effect on the relationship between city and senior government: this was the case in the United States between 2016 and 2020 due to the Trump administration's animosity to city environmental programs, and it is currently the case with Belo Horizonte and the Bolsonaro government in Brazil.

Table 4-9. *Summary of key city frameworks and policy areas.*

City	Primary internal sustainability frameworks & documents	Select external *& waste related* frameworks	Carbon neutrality target	Key policy areas	Areas of limited authority
Belo Horizonte	Belo Horizonte Master Plan "Supportive Capacity"	SDGs UN Habitat *"Ecofriendly"*	No target, reduction by 2030	BRT, Transit Oriented Development, FAR Incentives, Flood mitigation.	
Copenhagen	2025 Climate Plan Circular Copenhagen Plan	SDGs *Circular economy*	2025	Renewable Energy, Recycling, Cycling infrastructure	Building codes, major roads
Helsinki	Carbon neutral Helsinki Sustainable Helsinki	SDGs *Circular Economy*	2035	Carbon neutrality, change of heating source	
Lahti		*Circular economy*	2025	Biomass energy	
Lakewood, Colorado	2015 Sustainability Plan	STAR Communities *Zero Waste*	50% below 2007 by 2050	Sustainable Neighborhoods Program	Transit, Energy Utility District, few job centers located within city

Melbourne	Climate Change Mitigation Strategy to 2050 Nature in the city	SDGs, CDP, Still assessing for material flows	Scenarios from 2043 to 2050	Energy, emissions, building, transport, food, waste, climate hazard infrastructure and action	Metro region beyond central city, need change at the state and national level
Paris	Climate Action Plan 2050	*SDGs* *Circular economy*	2050	Social housing, electric bikes, public transport, green roofs, car reduction	Metro region beyond central city
Portland	Climate Action Plan	Paris Agreement	No target, 80% by 2050	Financing incentives, citywide densification	Public Health, Land-Use, Solid Waste, Bridges
San Francisco	0-80-100-Roots SF Climate Action Plan	Paris Agreement Donut Economics *Zero Waste*	2045	Recycling, transit, parking, green building code, financing incentives	Metro region beyond central city
Stockholm	*Environment Program*	*SDGs* *Waste hierarchy*	2050	Congestion charge, waste sorting	
Toronto	Transform TO	*SDGs* *Circular economy*	2050	Zero emissions buildings, energy, water	

Table 4-10. *Overview of city relationships to senior government and areas of tension and resolution.*

City	Relationships to regional and senior government	Tension / limitations	Resolution /successes
Belo Horizonte	Lack of support from current federal administration.	Very limited financial resources. Significant social problems take priority	City leverages non-financial resources, such as the ability to dictate BRT development and land-use policy
Copenhagen	National government has authority over building standards and major roads: More aggressive standards for multi-family buildings and congestion charging difficult to pursue. EU regulations mean city procurement for biomass must be EU, rather than local, in scope.	Mandates require utility investments in renewables and recycling to break even. Jurisdiction over key issues shared with national government.	Climate and Circular Economy plans form a unified foundation across government.
Helsinki	Aligned to the national government, the city had a leading role to the country carbon neutrality target	Less tension and barriers, but tension in money and resource allocations	Discussions of the city council and with civil servants, education program from the youth to elders
Lakewood, Colorado	Lakewood is a suburb of Denver and is representative of the regional "average". There is a working group of "Front Range Sustainability Directors" who share expertise and compare programs. Colorado State government has recently become bullish on sustainability questions, though this means that the city's role has been reduced.	Sustainability division is very small. Does not have jurisdiction over energy utilities, transportation, or major job centers. Gov. structure, with weak mayor and strong council, makes change difficult to implement. City council is relatively conservative.	City able to leverage its position as an intermediary between large cities and smaller suburbs of the region. City focused on facilitating community-level action. This allows for action outside of gov. and creates community support for the sustainability division and its program.
Melbourne	Known share of responsibility toward climate reduction targets	Obtaining resources toward sustainability	Focus on economic arguments that sustainability is in everyone's best interest.
Paris	France is highly centralized in Paris, and there is a clear and direct relationship with the regional and national governments.	Fewer tensions than before. Associations think it does not go fast enough.	Solution with co-benefits for everyone, spectrum of actions to remove sacrifices.
Portland	Relationship with Multnomah County, with authority over public health and bridges, is key. Climate Plan is a joint plan. Metro (Regional Planning Agency) has authority over Land-Use planning and solid waste and is also a key player. Metro and State are both more rural and conservative than Portland itself, making change difficult.	Metro and state do not share same commitment to sustainability. The City Government's structure, with a weak mayor, strong council, and no city manager, makes change difficult.	City-wide consensus on the importance of sustainability. High government inertia means achievements are difficult to reverse.
San Francisco	Good relationship with State government, as values and incentives are mostly aligned. Regional planning agencies are weak, but good regional cooperation in terms of transportation and expertise-sharing. Regional tensions in relation to the housing crisis.	Limited ability to raise revenue for initiatives. Fragmented regional government makes regional change difficult.	Good relationships with grassroots organizations. Consolidated city/county government gives San Francisco significant authority within its borders.
Stockholm	Aligned with national and European Union goals	Not many tensions since 1972 commitment on resource saving and traffic.	Communication, balance of centralized and decentralized solutions, wish to demonstrate solutions.
Toronto	Partnership with the governments	The scale of the problems, fact that city needs to collaborate with other levels of government, resistance to change.	Focus on innovation, new actions, partnership, being first, patience.

Canadian cities

Key topics from interviews with Canadian cities are summarized in Table 4-11. A major trend is that all cities included in the interviews are aiming for carbon neutrality by 2050, although none are implementing consumption-based emission accounting. Unlike many of the global cities interviewed, no Canadian city other than Toronto has embedded the Sustainable Development Goals into its government or climate plans. In Montreal, these goals were a priority in the previous plan, but it is not the focus of the current Climate Plan. Another major difference between Canadian and other world cities is with regards to public involvement: although public participation is still present in Canadian cities, much of the focus is on one-way communication rather than two-way outreach.

There are also differences in approaches regarding the interplay between rules and regulations: Edmonton and Vancouver have both incentives and regulations, using education to help implement the latter. Montreal focuses on incentives, particularly for electric vehicles. Vancouver and Montreal each have a city charter that enables incentives and regulations, whereas the city charter in Halifax is more limited in this regard.

***Table 4-11**. Summary of interviews with Knowledge Holders in Canadian cities.*

Cities	Current Focus	Materials and Energy	Relationship to Senior Government	Theme 1: Tensions	Theme 1: Resolution
Edmonton	City recognizes the concept of an ecological limit and has defined a carbon budget.	City has an energy transition plan.	Main alignment is with the federal government.		
Halifax	Environment	Aim is zero landfill waste by 2050, reduced energy and thermal demand in buildings by 50% by 2040, and reduced energy in water treatment	Provincial and federal government are part of the 250 members of the stakeholders meeting.	Tensions result from a lack of a local common definition of sustainability principles, and private utilities have different stakeholders.	Halifax supports frequent communication, stakeholders' meetings and sharing of success stories.
Montreal	Focus is currently on the ecological transition and the protection the biodiversity.	Zero-waste lifestyle is promoted. Focus is on materials and energy flow in important sectors, and an aim for low carbon materials in infrastructure.	Alignment of actions towards provincial and federal goals.	New Climate Plan was just launched, tensions expected in the implementation.	City officers work upstream to prevent tension, they value communication, and they wrote a tension & resolution plan.

Toronto	Ambition of being the most sustainable and fastest city to change in the world.	Circular economy	Partnership with governments	The scale of actions, cannot do it alone, not in control, resistance to change	Focus on innovation, new actions, partnership, being first, patience
Vancouver	Director of sustainability recognizes the limit of the earth-carrying capacity, while city focus is on climate.	Materials and energy flow analysis performed by the city. Zero waste and net zero buildings are targets.	Currently a good alignment at the local, provincial, and federal levels, though discontinuities have happened in the past.	Tensions are traced back to the fossil fuel lobby and the "not in my backyard (NIMBY)" attitude.	Focus on win-win solutions.

4.4. Synthesis

4.4.1. Synthesis Overview

A synthesis of the two themes of i) measurement and ii) management points to important insights about how humanity can achieve viable mitigation and adaptation responses. This research has important implications for Canada, a country that comprises a high-consuming culture living in a highly urbanized context. With 80% of its population living in cities, the sustainable city agenda represents an important opportunity for Canada to unlock transformative change which requires senior government efforts aligned with clear and comprehensive sustainability goals. In the global context, Canada still has a credit of resources per capita, as highlighted by the ecological footprint indicator (Global Footprint Network, n.d.-c). In this section, we discuss how cities are approaching living within the Earth's carrying capacity, cities achieving absolute reduction in 2010-2020, best practices and policies from the literature and knowledge holders, and limitations and gaps.

The first theme of measurement explores how cities are engaging with the scientific evidence about Earth's carrying capacity in order to understand their role in both effecting and being affected by changes associated with human-induced ecological change. This information was organized and presented through a variety of urban sustainability frameworks that cover at least one of five domains of energy and material consumption in cities: food, buildings, consumables and waste, transportation, and water. The frameworks that align with the ECC and are applicable at the city scale are: International Ecocity Standards, One Planet Living/Cities, Planetary Boundaries, Urban Metabolism, Doughnut Economics, C40 Thriving Cities, Living Community Challenge 1.2, The Natural Step, Transition Network, Global Footprint Network, and Circular Economy. The frameworks and metrics for measuring living within Earth's carrying capacity enabled identification of leading cities and communities achieving absolute reductions for the city as a whole, as well as on a per capita basis. Examples of cities that reduced their impact in the 2010-2020 period using these frameworks are Amsterdam, Edmonton, London, Melbourne, New York, Paris, and Vancouver. The fact that several of the sustainability frameworks identified included the goal of living within ECC demonstrates that consideration of planetary limits in urban sustainability assessment is on the rise. Cities are looking for ways to differentiate themselves and to show that they are sustainability leaders. Living within ECC is a strong sustainability statement.

The second theme of management explores governance models that determine a society's management systems and structural elements, including those related to assignment of power and authority, decision-making, and response to changes, such as from climate change and other major global ecosystem disruptions. Taken together, these two themes – measurement and management - help us understand how cities are employing scientific evidence and mobilizing resources to tackle the challenge of living within Earth's carrying capacity.

There is a gap in both the academic and grey literature related to the link between governance models and Earth's carrying capacity. It is not clear if city governments recognize how their governance model is – or is not – contributing to living within Earth's carrying capacity; this information is not readily available. It appears therefore that the impacts of governance model are either not documented or not known.

The connections between the governance model, municipal sustainability policy, and a city's ability to achieve absolute reductions are still missing. Other factors, such as local culture and identity, pride in the city and surrounding environment, and the desire to be seen globally as a sustainability leader, may be contributing to a city's perceived success as much as governance but this has been difficult to determine for the shortlisted cities in this study. Overall, academic literature is not yet robust enough to outline with certainty the impacts or effective implementation of governance models in achieving absolute reductions to live within Earth's carrying capacity.

The results from research into Theme 1 were used to triangulate a short list of leading cities working with sustainability frameworks and selected metrics. These cities each demonstrate absolute reductions in emissions, and research was then conducted into their urban and sustainability policies in an effort to identify trends and best practices. There is a key set of baseline policies which are close to universally adopted, and a broader collection of policies which build upon these, and whose adoption depends on the local governance context. However, as with governance models, the connection between implementation of ambitious policies and actual reductions in emissions is difficult to determine. Interviews were also conducted with key knowledge holders, providing accounts of the tensions currently being experienced, the resolutions to previous tensions, and the relationships between cities and senior governments. These provided a deeper understanding of the role of local government context with regards to the implementation, or non-implementation, of frameworks or policies. Alternative pathways hold promise for solutions worth investigating, examples of alternative pathways in shortlisted cities with known framework and absolute reduction.

4.4.2. Identification of Cities Achieving Absolute Reduction

Among the cities identified using carbon footprint analysis (CFA), most are located in Global North countries and rely on a service-based economy (generally involving Scope 3 in addition to Scopes 1 and 2 emissions), qualifying them as "consumer cities", as opposed to "producer cities" (C40 Cities, 2017). However, as shown in Table B-6 in Appendix B, either the frameworks used do not account for Scope 3 emissions, or when they do, a lack of regulation in the reporting of Scope 3 requirements hinders a comprehensive carbon footprint evaluation of the cities (Moran et al., 2018; Wiedmann et al., 2020). This incoherence between cities' typology and the methodology used for their sustainability assessment, or the lack of completeness of the latter, can be problematic for the risk in misrepresentation of their entire impact and burden shifting to other regions can be significant (Balouktsi, 2020; Ghaemi & Smith, 2020; Ortega-Montoya & Johari, 2020). This shortcoming could be diminished by using a more holistic indicator

such as ecological footprint analysis (EFA) that offers a more complete representation of the system, thus avoids the risk of trade-offs between different natural assets.

The EFA method is still emerging and few cities have evaluated their footprints consistently over time with their own assessment resources, with the majority of data coming from academic articles. It could be that a perception among urban decision makers that this framework is too complex to use explains this gap in time series evaluation and lack of broader use at urban scale as a monitoring indicator (Beloin-Saint-Pierre et al., 2017; Moore et al., 2013).

As the Global South urban population and the ensuing environmental pressures are projected to increase, literature gaps on Global South urbanization risk to undermine efforts for global environmental mitigation, for this domain is widely dominated by western case studies and theories (Nagendra et al., 2018).

4.4.3. Effective Urban Policymaking: The Difficulty in Assessing Causality

One of the goals of this project is to learn whether there are commonalities between the policy approaches of the shortlist cities, and if so, to consequently apply this knowledge of global best practices to a Canadian context. This requires both an understanding of the policy landscape in the shortlisted cities, and an understanding of the relative impact of these policies on urban sustainability.

The first step is to determine the extent to which policymaking in our shortlisted cities has had an impact on urban sustainability: the goal here is to distinguish between cities which are potentially responsible for their reductions in impact, and the cities whose reductions are the result of secondary factors outside of the city's control. Figure 4-4 shows how this distinction can be visualized: we are primarily interested in identifying the cities which are directly responsible for their reduced impact and can therefore be assumed to represent more innovative or bold policymaking.

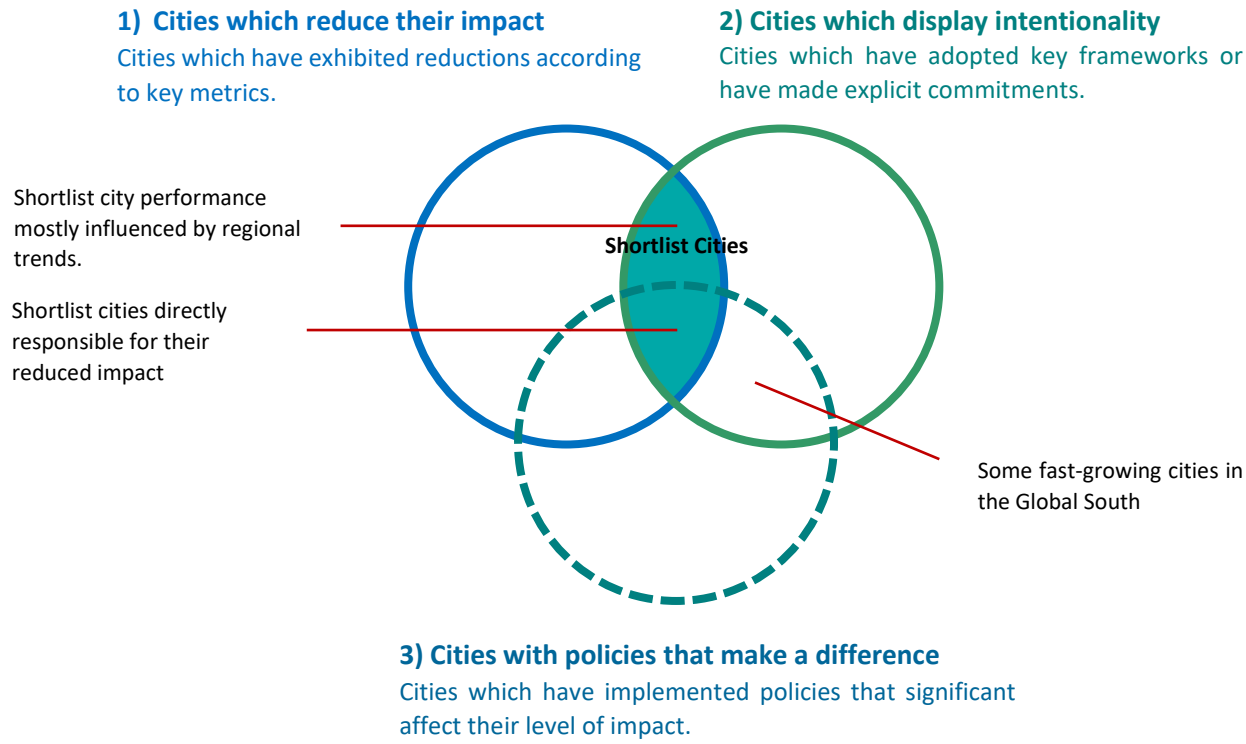

Figure 4-4. *An overview of the properties exhibited by cities, and what the shortlist is or is not able to distinguish between.*

There are many reasons why a city might be reducing its environmental impact which are external to city policy, and which therefore risk overshadowing any causal link between policies implemented and overall outcomes. The analysis in Appendix C begins to address these concerns, however, fully identifying, evaluating, and eventually controlling for these external factors will require further research.

Possible non-city factors affecting the long-term environmental trajectories of cities:

1. **Demographic shifts.** Population growth, at a fixed per capita rate of resource consumption, will result in increased environmental impacts. Conversely, declining populations will result in declining impacts despite maintaining high per capita consumption.
2. **Shifts in economic trajectory.** Growing incomes tend to increase rates of individual consumption, especially in existing low-income regions (Fernández-Amador et al., 2017). Economic downturns may result in lower consumption rates.
3. **Changes to national or regional policy.** National and regional governments tend to have more significant regulatory powers than municipal governments and are therefore able to adopt policies which are broader in scope and more significant in their outcomes. Carbon taxes and changes to transportation funding could have a more significant effect on urban consumption and emissions patterns than local policies.

4. **Changes to national or regional energy mix.** As energy grids increase their share of renewables, either as a result of national investment or technological development, energy-related emissions may decrease, thereby reducing urban emissions without there being any change in the city itself.

In addition to these four factors, there are others which can affect the shorter-term environmental trajectories of cities, such as disruptive events like earthquakes and pandemics (Le Quéré et al., 2021).

An evaluation of the external factors which influence city trajectories also sheds light on why cities from the Global South are almost entirely omitted from the discussion of shortlisted cities. Although most cities from the Global South are limited in the scope of their policymaking relative to their peers in the Global North, either due to a lack of financial resources or governance capacity, it does not mean that there are not many examples of successful and innovative policymaking coming out of the region (this is especially true for policies which take local constraints into account, or policies which provide economic or welfare co-benefits) (International Transport Forum, 2019). Nevertheless, the combination of demographic growth and rising incomes which characterizes much of the region will overshadow any policy-driven reductions in environmental impact.

4.4.4. Trends in Urban Policymaking among Shortlisted Cities

Identifying trends in policymaking amongst the shortlisted cities allows for both lessons to be learned about what constitutes best-practice policymaking, and to further distinguish between cities which are either more or less responsible for their impact reductions. An initial result of this effort is the conclusion that shortlisted cities have all implemented a similar baseline set of policies on paper. A baseline set of urban policies, or policy types, include those which are shaded in Table 4-12.

Table 4-12. *Shaded cells are common forms of policies implemented among shortlisted cities. White cells feature policies which occur in several cities but are not universal.*

	Policy Area			
	Food	**Transport**	**Buildings**	**Consumables and waste**
Education	• Eat local campaigns • "Meatless Mondays"	• Route planners • Bicycle and transit Education campaigns	• Energy conservation campaigns	• Recycling education campaigns
				• "Buy local" campaigns
Incentives	• Space for farmers markets	• Rebates and tax credits for efficient vehicles	• Subsidies for retrofits • Green roof subsidies	• Door-to-door collection
	• Subsidies for urban agriculture	• Micro mobility Subsidies	• Smart metering schemes	• Free or reduced cost recycling • Rebates for waste minimization
Capital spending		• Public transport infrastructure • Bicycle lanes	• Eco-districts • District heating • Municipal renewable energy facilities	• Recycling facilities
		• World class bicycle infrastructure		• Distributed neighborhood facilities
Regulations		• Congestion charges • Pedestrianization initiatives • Parking reforms	• Green building codes	• Bans on non-recyclables. • Fines for not recycling. • Carbon taxes
			• Green roof requirements • Urban growth boundaries • Urban densification	

An Emphasis on Incentives over Regulations

A common feature of these baseline policies is that they are almost entirely non-coercive in nature, and focus principally on education programs, incentives for individuals and businesses, and capital projects where money is spent on infrastructure relating to transportation, renewable energy, or waste processing. To the extent that regulations are present, they are generally targeted at future development via building codes.

The prevalence of minimally disruptive or minimally coercive policies is also facilitated by the relative wealth of the cities themselves: widespread incentives are possible and are financial in nature, and capital projects are designed to minimize the demands placed on residents (i.e., underground tunneling for metros, single stream recycling). Examples of innovative policies which are more disruptive to a city's residents and place greater burdens or requirements on them often emerge instead from the Global South, where budgetary constraints lead to creativity and a greater emphasis on regulation. Examples include Taiwan's demanding recycling policies, Latin America's policies regulating car use via license plate numbers, Belo Horizonte's drainage box requirements, Nairobi's transit reallocations.

Baseline policies (Group 1) vs Notable and Unique (Group 2)

There is a clear split between 2 groups of policies (Table 4-13). The first represents the baseline policies, which are widespread in their adoption but differ significantly in the extent of their implementation. These policies have a low barrier to entry because they can be implemented in a variety of ways, with scopes ranging from limited to ambitious. Examples include financial incentives, which can be increased or decreased on a sliding scale, or bicycle infrastructure, with networks which range from limited to extensive, or green building codes, which can feature more or less stringent requirements.

Policies which represent either real costs to individuals or real restrictions to individual freedom, and are thus more ambitiously regulatory in scope, are not common among shortlist cities. This category (group 2) includes policies such as congestion charges, explicit bans on non-recyclable products, and policies which directly increase the cost of utilities and recycling fees. Ambitious land-use changes, such as urban infill and residential densification, also fall in this category. It is, however, worth noting that most policies which levy direct financial costs on consumers (environmental tariffs or 'ecotaxes') outside of the domains of transportation or waste management are almost exclusively implemented at the national level. To date, Singapore is the only city identified in this report which has implemented a carbon tax, a direct consequence of its status as a city-state.

Table 4-13. *Summary of Group 1 and 2 policies.*

Group 1 Policies: Baseline policies, exist on sliding scale	**Group 2 Policies:** Notable and Unique, "All or nothing"
• Low barrier to entry • Policies implemented on a sliding scale, from limited to ambitious. • Can fluctuate according to whims of city politics and/or budget	• High barrier to entry • High upfront cost of implementation, either $ or political • Makes the news
Examples: • Financial incentives • Transport investment • Bicycle lanes • Energy/water efficiency incentives • Building codes • Educational initiatives • Recycling schemes	**Examples**: • Congestion charges • Reclaiming urban space from cars, i.e. pedestrianization • Widespread bicycle network • District heating systems • Bans on categories of consumables • Green roof/rooftop renewable requirements • Citywide urban densification

5. Implications

The transition to sustainability and living with Earth's carrying capacity (ECC) requires: a) adopting systemic thinking to have a full picture of the situation before making decisions for the future and b) embracing a fundamental principle: we are *not apart* from nature, we are *a part of* nature.

Hints to solutions

A good start to this transition is for cities to protect the ecosystems they rely on. They support large populations on limited land and must better understand the value of the ecosystems they are part of and the land their populations depend on beyond their boundaries. In the dominant paradigm, real estate development is valued much higher than ecosystems because the perception of ecosystems value does not account for billions of years of evolution. **We need therefore to value ecosystem services in a systemic way to improve understanding of their true value** and, subsequently, of the relative value of real estate. Municipalities such as Gibsons and West Vancouver in B.C. are proactive examples in ascribing value to ecosystem services.

Most sustainability frameworks undermine the potential for cities to achieve living within ECC. We need not only **stronger sustainability goals and more comprehensive tools**, but also to clarify the gaps and better quantify degrowth and new growth objectives. Currently, climate action is the priority but cities need holistic sustainability action plans. Attempts to improve efficiency or achieve circularity must be tied to the magnitude of reductions required by high-consuming cities. Those that are considered as more sustainable are reducing by 10% but this is not enough; we need reductions of 80-90% – and fast.

Likewise, the inequitable distribution of costs and benefits is important to address, as a small proportion of the global population created an unsustainable future: the wealthiest 10% account for 48% of global emissions and the bottom 50% account for only 7% of global emissions (UNEP, 2020). **We need broad ecoliteracy and sustainability literacy and overall greater clarity about biophysical requirements for living within the ECC.**

The fact that carbon footprint is the most used indicator for sustainability despites its narrow scope and incomplete urban standards suggests an **inadequate representation of urban impact worldwide**. This directly hinders policy-makers from making the urgent decisions required. Indeed, the use of a more comprehensive indicator or a more complete methodology for GHG emissions' attribution to assess cities' impact on their ecosystem would allow for a better comprehension of the situation and promote a more holistic monitoring of the politics and actions aimed at reducing urban pressure on the environment (for more details, see sections 4.1 and 4.3).

It is **important that cities measure both normalized and absolute reduction**. Whereas a per capita reduction shows higher efficiency, perhaps linked to environmental policies or actions such as the shift in energy grid or process optimization, an absolute reduction signifies a decrease in overall impact, accounts for demographic changes, and demonstrates a strong sustainability and alignment with ECC principles. As an example, one of the cities analyzed using EFA, Cairo, displays a reduction its per capita footprint by 1% but, when demographics are factored in, the result is an absolute increase of 50% explained by a 47% population growth.

In parallel, cities need to reconnect with the five domains of consumption (food, buildings, consumables and wastes, transportation, water) (for more details, see sections 4.1.3 and 4.4). **Better, consumption-**

based accounting of our materiality is required, starting with regular and comprehensive analysis of materials and energy flows. Circular economy is a framework that can help to this end but we must keep in mind that, from a thermodynamic perspective, every cycle needs an input of energy to restart and that there are limits to circularity.

Policy coherence among multiple levels of government and with global actors can help enhance municipal decision-making processes and achieve sustainability goals particularly in areas over which cities may not have full control. **Policy alignment across all municipal departments** is also highly recommended to assess whether long-term ecological and social costs are being factored into operating decisions. Local, regional, and senior governments must therefore align their goals and policies to shift the billions of dollars still being invested in unsustainable activities.

Overall, **cities need to follow a resilient-based "shrink, share, and regenerate" approach.** Reduced demand on energy and material resources, coupled with equitable sharing of the benefits of such reduction and a sustained effort to regenerate nature, informed by traditional and Indigenous knowledge, is the ultimate alternative pathway toward living within ECC (for details, see section 4.4).

In practice, the shift toward a new paradigm and belief system means:

- a systemic reconfiguring of urban land use planning to reduce resource demand by developing:
    - mixed use compact communities with open and walkable space, public transport options, and maximized forest canopy, to prioritize pedestrians and urban nature;
    - space for urban and peri-urban agricultural production with methods such as permaculture and agroforestry – promising approaches that do not rely solely on technology but aim to move agriculture away from pesticides and reconnect us with natural cycles providing a better understanding of food production (note however that even regenerative agriculture methods are not enough to ensure self-reliance or food security; absolute reductions in demand are needed too);
- equitable redistribution of the savings resulting from the reduced resource demand coupled with education programs to promote the goal of living within ECC (and spur additional reduction of absolute impact); and
- continuous investment in eliminating waste and restoring and regenerating natural capital (instead of investment in more consumption).

In addition, **important climate action initiatives such as the Race to Zero and the One Planet Cities Challenge offer excellent opportunities for cities to amplify their local efforts while being part of global networks of urban change-makers**. The Race to Zero[2] is a global UN-led campaign that mobilizes thousands of actors such as businesses, cities, regions, investors, and higher education institutions to commit and adopt practices toward net zero carbon emissions by 2050 at the latest. The One Planet Cities Challenge[3] is a WWF-sponsored campaign that aims to support cities in accelerating their climate transformation and showcase best practices.

[2] For more information: https://unfccc.int/climate-action/race-to-zero-campaign

[3] For more information: https://wwf.panda.org/projects/one_planet_cities/one_planet_city_challenge/

Hierarchy of actions to move forward

A **hierarchy of actions from the individual to the community, city, and other levels is the way forward** to achieve adaptation and transition to an increased consciousness of living within ECC. At the individual level, the reasoning is oriented toward the actions that better promote our health. For example, citizens need to reflect on changes they can make to contribute to living within planetary means and advocate for local healthy food and more active transportation options. Communities must advocate for more green space, canopy cover, and active and public transport and undertake materials and energy flow analysis. **Cities with support from citizens, businesses, and senior governments can make bigger change happen sooner. There are already many tools, indicators, guidelines, and best practices in place and all urban actors need to consolidate their actions in a holistic approach.**

Two examples of hierarchical thinking at the city scale are around waste management and transportation, with the latter having a big share of carbon emissions in Canadian cities, especially when operating on non-renewable energy. The transportation system must be oriented toward the human scale first and thus planning should take this order into account: pedestrians, cyclists, public transport, good mobility, and lastly the automobile. Similarly, waste management should be thought of through this hierarchy of action: rethink, reduce, reuse, repurpose, and recycle. The advantage of such thinking is that it promotes both resource saving and profit generation. For example, the city of Toronto is aware of savings created when the market rewards of electric cars for example and they do not believe that additional incentive is needed. The city of Toronto also has a higher capital to operational budget ratio than many cities. This information was not available for many cities and cannot be discussed further. When incentives generate rewards at the municipal level, the aim is to transform the savings into investment toward living within the ECC.

Research implications and gaps to address

This synthesis highlights a number of research questions concerning gaps we need to address in order to live within ECC:

- The level of reduction needed to achieve living within planetary capacity must be assessed quantitatively and qualitatively.
- Thorough and systemic estimation of the value of natural assets.
- As cities achieving absolute reduction have adopted the same policies as other cities that do not, an assessment of the degree to which cities are pursuing such policies is required.
- The identification of the signal for cities to reduce their emissions and consumption must be more visible.
- More consumption-based accountability – and research around it – is needed.
- We need to tackle the economic system and identify best practices to finance the transition.
- The connection between the main factors of living with ECC must be better documented. These factors include: population changes (e.g., natural vs immigration-induced); frameworks, governance models, policies, and actions by cities; and the resulting absolute reduction of resources.
- Finite planetary resources dictate a finite population that can be supported. However, population is treated as an uncontrollable variable, if mentioned at all in frameworks and policy. This is a gap as direct policy and metrics may be needed to limit population within ECC.

- Equity considerations in terms of wealth, socio-economic status, etc. need to be addressed to ensure equitable access to resources and the savings from sustainability action.
- The best practices for a complete integration of sustainability at the city level need to be researched and widely disseminated.
- Similarly, for the best practices to regenerate natural assets, to circulate the renewable and non-renewable resources.
- A holistic assessment for policy alignment is required as it can make a difference.
- We must ensure that the planning frameworks and the measuring tools are keeping us on a sustainable path.
- There is a need to establish the extent to which alternative approaches are scalable and adaptable to Global North, wealthier, and non-Indigenous communities toward the goal of living within ECC.
- The concept of living within ECC must be communicated to a wider audience.

6. Conclusion

City operations require constant provisioning from ecological services required for human survival in the forms of air, water, energy, food, fibers, and minerals, as well as essential waste removal services through dispersion, dilution, and absorption in a variety of solid, liquid and gaseous forms. The physical movement of energy and material flows from nature to cities and back to nature can be assessed and measured through a variety of scientifically based frameworks and metrics. These help cities align their interests for operating sustainably and provide indicators for tracking progress.

Whether and how humanity, and by extension those responsible for operating its cities, responds to scientific evidence collected through various sustainability metrics is determined in large part by social and cultural beliefs. The belief systems inherent in dominant world views are embedded in the economic and socio-political systems by which cities and society are governed. These give rise to the social organizing features that impact cities through regulatory and policy frameworks, commodity prices, labor markets, and social contracts by which people agree to be governed, and through which people continue to participate in labor and taxation regimes in exchange for provision of social services such as education, healthcare, and military protection. So, to tackle the underlying causes of climate change and ecological crises, we need to use systems approaches that re-position human beings in ecosystems.

This knowledge synthesis report assesses the state of literature and practice on both frameworks and metrics for living within Earth's carrying capacity (ECC) and on policies and best management practices of cities achieving absolute reduction in the 2010-2020 timeframe. The intention of this synthesis is to support the Government of Canada in use of synthesized evidence in decision-making for policy and practice and in the development of future research agendas. The synthesis of the findings from the themed literature reviews, supplemented with scientific-based evidence and combined with socio-cultural practices from the knowledge holder interviews, aims to promote actions toward ECC.

A highlight of this knowledge synthesis is the huge potential of research on living within ECC. The concept of planetary limits must be acknowledged and emphasized. Climate metrics are dominant in practice by city administrations worldwide, whereas more research with the Material and Energy Flow Analysis methodology is needed, to link climate metrics to energy and material flows. At the city level, a more holistic approach is to consider the GHG, energy, and materials flows within the city boundaries. There is a need for more action to ensure absolute reduction of impact. Policies are lagging for several reasons, notably lack of public support from misunderstanding the links between climate impacts and local action, as well as the still emerging nature of urban climate policy assessment and development.

The overarching goal is to have a thriving life, sustainable and equitable, for human beings on Earth. We need to reconnect to the boundaries of our living system to learn how to regenerate using the natural biophysical forces, limiting the input from non-renewable resources. The inequitable distribution of the cost and benefits of meeting global sustainability challenge is surfacing as an important discussion. There is increasing recognition that averages mask the reality of medians. Meanwhile, economic growth remains a paramount objective for most cities while, at current levels of energy and materials throughput, they keep consuming at rates incompatible with Earth's regenerative capacity. Most sustainability frameworks undermine the potential for city success mainly because they are untethered to global ecosystem stability thresholds. Attempts to improve efficiency or achieve circularity must be tied to the magnitude of reductions in current consumption and waste outputs needed by high-consuming cities if humanity is to live within ECC.

As part of the knowledge holder interviews, a variety of responses was received and there were several trends in the responses. Leading cities reported confidence in achieving their climate targets. However, they are less confident that they are living within Earth's carrying capacity as this concept is rarely used. A global consensus is emerging around the circular economy concept for materials and energy flow, though it is important to recall that this framework does not consider the limits of the earth's carrying capacity. The hierarchy of action can facilitate decision-making, starting with simple gestures like waste sorting and transportation choices. Cities are recognizing that they have the power to reduce their demand on nature and they must reduce their consumption. The allocation of financial resources is a common source of tension, while there is more agreement on the general concept of sustainability and caring for the environment. Cities such as Paris and Helsinki are recognizing that their purchasing power can make a difference and are thus adopting sustainable procurement policies. Integrating sustainability leadership across departments remains an effective approach among leading cities achieving absolute reduction. There is less tensions in cities when they are aligned with the senior government.

Globally cities' emissions reductions are insufficient to achieve global climate stability as only a handful of cities are achieving reduction. Economic growth is still too often divorced from recognition that cities are consuming at levels incompatible with global carrying capacity. The majority of city resources invested in perpetuating unsustainability. Changes in political leadership often results in a discontinuous pursuit of goals. Moreover, cities can only go as far as the senior government can support. Cities must recognize their role as the most suitable level of action to achieve living within ECC and invest in sustainability practices that can result in meaningful reductions in emissions as well as in energy and material consumption. This requires increased awareness of non-local matters and particularly a deep understanding of the planet's ecological limits in conjunction with the need to ensure equitable distribution of both costs and benefits at the global scale. It also requires policy coherence among the various levels of government and policy alignment across municipal departments to assess the level of investment dedicated to maintaining unsustainable infrastructure and to ensure that long-term socio-ecological costs are being factored into operating decisions.

Cities need to embrace one-planet-aligned frameworks and tools, increase local government capacity, and ensure collection of reliable and timely data for the local scale. In addition, Global North communities must learn from alternative development pathways grounded in strong sustainability principles, collaborative governance, resource regeneration, and the ecological worldview upheld by Indigenous (and some non-Indigenous) communities around the world.

7. Knowledge mobilization activities

To share the findings of this research synthesis project, the following knowledge mobilization activities have been undertaken by the researchers:

- Two discussion symposiums with the project collaborators in 2020 and 2021;
- Two NSERC Science Odyssey virtual events - in English and French - in May 2021;
- One article written for the Canadian Society of Civil Engineers conference in May 2021.

Mobilization activities planned after release of this report:

- Report and appendices posted on the websites of the researchers' institutions (BCIT and ETS);
- Two articles for peer-reviewed journals, one each on research Theme 1 and Theme 2;
- One French language article for an open access journal published in Canada;
- An article in both French and in English for the ETS Substance magazine;
- A webinar on the project findings hosted by the BCIT Centre for Ecocities in early 2022.

Bibliography

Aldaya, M. M., Chapagain, A. K., Hoekstra, A. Y., & Mekonnen, M. M. (2012). The Water Footprint Assessment Manual. In *The Water Footprint Assessment Manual*. Routledge. https://doi.org/10.4324/9781849775526

Almond, R. E. A., Grooten, M., & Peterson, T. (2020). *Living Planet Report 2020—Bending the curve of biodiversity loss*. World Wildlife Fund.

Arioli, M. S., D'Agosto, M. de A., Amaral, F. G., & Cybis, H. B. B. (2020). The evolution of city-scale GHG emissions inventory methods: A systematic review. *Environmental Impact Assessment Review*, *80*. https://doi.org/10.1016/j.eiar.2019.106316

Association Bilan Carbone (ABC). (2017). *Methodological guidelines—Bilan carbone—Accounting principles and objectives (V.8)*.

Audrin, T., Apparicio, P., Séguin, A. M., & Gelb, J. (2020). Bruit aérien et équité environnementale dans les quatre plus grandes métropoles canadiennes. *Canadian Geographer/Le Géographe Canadien*, *64*(1), 155–168. https://doi.org/10.1111/cag.12571

Baabou, W., Grunewald, N., Ouellet-Plamondon, C., Gressot, M., & Galli, A. (2017). The Ecological Footprint of Mediterranean cities: Awareness creation and policy implications. *Environmental Science and Policy*, *69*, 94–104. https://doi.org/10.1016/j.envsci.2016.12.013

Balouktsi, M. (2020). Carbon metrics for cities: Production and consumption implications for policies. *Buildings and Cities*, *1*(1), 233–259. https://doi.org/10.5334/bc.33

Barbier, E. B. (1987). The Concept of Sustainable Economic Development. *Environmental Conservation*, *14*(2), 101–110. https://doi.org/10.1017/S0376892900011449

Barrau, A. (2019). *Le plus grand défi de l'histoire de l'humanité: Face à la catastrophe écologique et sociale*.

Barrett, B. F., Horne, R., & Fien, J. (2020). *Ethical cities*. Routledge.

Batagan, L. (2011). Smart Cities and Sustainability Models. *Informatica Economica*, *15*(3), 80–87. https://ideas.repec.org/a/aes/infoec/v15y2011i3p80-87.html

Beatley, T., & Newman, P. (2013). Biophilic cities are sustainable, resilient cities. *Sustainability*, *5*(8), 3328–3345. https://doi.org/10.3390/su5083328

Beloin-Saint-Pierre, D., Rugani, B., Lasvaux, S., Mailhac, A., Popovici, E., Sibiude, G., Benetto, E., & Schiopu, N. (2017). A review of urban metabolism studies to identify key methodological choices for future harmonization and implementation. *Journal of Cleaner Production*, *163*, S223–S240. https://doi.org/10.1016/j.jclepro.2016.09.014

Biermann, F., Betsill, M. M., Gupta, J., Kanie, N., Lebel, L., Liverman, D., Schroeder, H., Siebenhüner, B., & Zondervan, R. (2010). Earth system governance: A research framework. *International Environmental Agreements: Politics, Law and Economics*, *10*(4), 277–298. https://doi.org/10.1007/s10784-010-9137-3

Biermann, F., Stevens, C., Bernstein, S., Gupta, A., Kabiri, N., Kanie, N., Levy, M., Nilsson, M., Pintér, L., Scobie, M., & Young, O. R. (2014). *Integrating Governance into the Sustainable Development*

Goals. POST2015/UNU-IAS Policy Brief #3. (p. 4). Tokyo: United Nations University Institute for the Advanced Study of Sustainability.

Bihouix, P. (2019). *Le Bonheur Était Pour Demain: Les Rêveries d'un Ingénieur Solitaire*.

Billi, M., Mascareño, A., & Edwards, J. (2021). Governing sustainability or sustainable governance? Semantic constellations on the sustainability-governance intersection in academic literature. *Journal of Cleaner Production*, *279*, 123523. https://doi.org/10.1016/j.jclepro.2020.123523

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: A new system of cross-scale spatial indicators. *Building Research and Information*, *40*(5), 592–605. https://doi.org/10.1080/09613218.2012.703488

Bringezu, S. (2015). Possible target corridor for sustainable use of global material resources. *Resources*, *4*(1), 25–54. https://doi.org/10.3390/resources4010025

Brondizio, E. S., Settele, J., Díaz, S., & Ngo, H. T. (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In *Debating Nature's Value* (Issue 6 May). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Burch, S., Gupta, A., Inoue, C. Y. A., Kalfagianni, A., Persson, Å., Gerlak, A. K., Ishii, A., Patterson, J., Pickering, J., Scobie, M., Van der Heijden, J., Vervoort, J., Adler, C., Bloomfield, M., Djalante, R., Dryzek, J., Galaz, V., Gordon, C., Harmon, R., … Zondervan, R. (2019). New directions in earth system governance research. *Earth System Governance*, *1*, 100006. https://doi.org/10.1016/j.esg.2019.100006

C40 Cities. (2017). *Consumption based GHG emissions of C40 cities*. https://www.c40.org/researches/consumption-based-emissions

C40 Cities. (2018). 27 C40 Cities Have Peaked Their Greenhouse Gas Emissions. In *Case studies and research methodology media pack*.

California Air Resources Board, California Climate Action Registry, ICLEI - Local Governments for Sustainability, & The Climate Registry. (2010). *Local Government Operations Protocol For the quantification and reporting of greenhouse gas emissions inventories—Version 1.1.*

Carrier, M., Apparicio, P., Séguin, A. M., & Crouse, D. (2019). School locations and road transportation nuisances in Montreal: An environmental equity diagnosis. *Transport Policy*, *81*, 302–310. https://doi.org/10.1016/j.tranpol.2017.09.010

Casey, A. (2021, May 14). What is the Carrying Capacity of Earth? How Many People Can it Hold? *Population Connection*. https://www.populationconnection.org/carrying-capacity-earth/

Castelnovo, W., Misuraca, G., & Savoldelli, A. (2016). Smart Cities Governance: The Need for a Holistic Approach to Assessing Urban Participatory Policy Making. *Social Science Computer Review*, *34*(6), 724–739. https://doi.org/10.1177/0894439315611103

Chaffin, B. C., Garmestani, A. S., Gunderson, L. H., Benson, M. H., Angeler, D. G., Arnold, C. A. (Tony), Cosens, B., Craig, R. K., Ruhl, J. B., & Allen, C. R. (2016). Transformative Environmental Governance. *Annual Review of Environment and Resources*, *41*, 399–423. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7326237/

Chen, G., Shan, Y., Hu, Y., Tong, K., Wiedmann, T., Ramaswami, A., Guan, D., Shi, L., & Wang, Y. (2019). Review on City-Level Carbon Accounting. *Environmental Science and Technology*, *53*(10), 5545–5558. https://doi.org/10.1021/acs.est.8b07071

Cole, R. J. (2015). Net-zero and net-positive design: A question of value. *Building Research and Information*, *43*(1), 1–6. https://doi.org/10.1080/09613218.2015.961046

Commonwealth of Australia. (2017). *National Carbon Offset Standard*.

Condon, P. M. (2020). Five rules for tomorrow's cities: Design in an age of urban migration, demographic change, and a disappearing middle class. In *Five Rules for Tomorrow's Cities: Design in an Age of Urban Migration, Demographic Change, and a Disappearing Middle Class*. https://doi.org/10.5822/978-1-61091-961-6

Courmont, A., & Le Galès, P. (2019). *Gouverner la ville numérique*. Presses Universitaires France.

Čuček, L., Klemeš, J. J., & Kravanja, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production*, *34*, 9–20. https://doi.org/10.1016/j.jclepro.2012.02.036

Cura, R., Cottineau, C., Swerts, E., Antonio Ignazzi, C., Bretagnolle, A., Vacchiani-Marcuzzo, C., & Pumain, D. (2017). The Old and the New: Qualifying City Systems in the World with Classical Models and New Data. *Geographical Analysis*, *49*(4), 363–386. https://doi.org/10.1111/gean.12129

Curtis, F. (2003). Eco-localism and sustainability. *Ecological Economics*, *46*(1), 83–102. https://doi.org/10.1016/S0921-8009(03)00102-2

D'Amour, C. B., Reitsma, F., Baiocchi, G., Barthel, S., Güneralp, B., Erb, K. H., Haberl, H., Creutzig, F., & Seto, K. C. (2017). Future urban land expansion and implications for global croplands. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(34), 8939–8944. https://doi.org/10.1073/pnas.1606036114

De Jong, M., Joss, S., Schraven, D., Zhan, C., & Weijnen, M. (2015). Sustainable-smart-resilient-low carbon-eco-knowledge cities; Making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, *109*, 25–38. https://doi.org/10.1016/j.jclepro.2015.02.004

Dernbach, J. C., & Cheever, F. (2015). Sustainable development and its discontents. *Transnational Environmental Law*, *4*(2), 247–287. https://doi.org/10.1017/S2047102515000163

Dong, X., Milholland, B., & Vijg, J. (2016). Evidence for a limit to human lifespan. *Nature*, *538*(7624), 257–259. https://doi.org/10.1038/nature19793

Dor, A., & Kissinger, M. (2017). A multi-year, multi-scale analysis of urban sustainability. *Environmental Impact Assessment Review*, *62*, 115–121. https://doi.org/10.1016/j.eiar.2016.05.004

Du Plessis, C., & Brandon, P. (2015). An ecological worldview as basis for a regenerative sustainability paradigm for the built environment. *Journal of Cleaner Production*, *109*, 53–61. https://doi.org/10.1016/j.jclepro.2014.09.098

Elhacham, E., Ben-uri, L., Grozovski, J., Bar-on, Y. M., & Milo, R. (2020). Global human-made mass exceeds all living biomass. *Nature*. https://doi.org/10.1038/s41586-020-3010-5

European Commission. Statistical Office of the European Union. (2018). *Economy-wide material flow accounts handbook: 2018 edition.* Publications Office. https://data.europa.eu/doi/10.2785/158567

Fernández-Amador, O., Francois, J. F., Oberdabernig, D. A., & Tomberger, P. (2017). Carbon Dioxide Emissions and Economic Growth: An Assessment Based on Production and Consumption Emission Inventories. *Ecological Economics*, *135*, 269–279. https://doi.org/10.1016/j.ecolecon.2017.01.004

Finnish Environment Institute (SYKE). (2021). *Calculating the greenhouse gas emissions of Finnish municipalities*.

Folke, C., Jansson, Å., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio*, *26*(3), 167–172. https://doi.org/10.2307/4314576

Ghaemi, Z., & Smith, A. D. (2020). A review on the quantification of life cycle greenhouse gas emissions at urban scale. *Journal of Cleaner Production*, *252*. https://doi.org/10.1016/j.jclepro.2019.119634

Gleeson, T., Erlandsson, L. W., Zipper, S., Porkka, M., Jaramillo, F., Gerten, D., Fetzer, I., Cornell, S., Piemontese, L., Gordon, L., Rockström, J., Oki, T., Sivapalan, M., Wada, Y., Brauman, K., Flörke, M., Bierkens, M., Lehner, B., Keys, P., … Famiglietti, J. (2019). *The water planetary boundary: Interrogation and revision*. https://doi.org/10.31223/OSF.IO/SWHMA

Global Footprint Network. (n.d.-a). *Footprint Standards—Global Footprint Network*. https://www.footprintnetwork.org/resources/data/footprint-standards/

Global Footprint Network. (n.d.-b). *Glossary*. https://www.footprintnetwork.org/resources/glossary/

Global Footprint Network. (n.d.-c). *National Footprint and Biocapacity Accounts, 2021 Edition*. https://data.footprintnetwork.org/

González, S. C., & Numer, E. (2020). What is climate governance. *United Nations Children's Fund (UNICEF)*, 43.

Greater London Authority. (n.d.). *London Energy and Greenhouse Gas Inventory (LEGGI)—London Datastore*. https://data.london.gov.uk/dataset/leggi

Green Dreamer. (n.d.). *A message from 10+ Indigenous leaders: Regenerative Agriculture & Permaculture offer narrow solutions to the climate crisis*. https://greendreamer.com/journal/indigenous-regenerative-agriculture-permaculture

Hachaichi, M., & Baouni, T. (2020). Downscaling the planetary boundaries (Pbs) framework to city scale-level: De-risking MENA region's environment future. *Environmental and Sustainability Indicators*, *5*, 100023. https://doi.org/10.1016/j.indic.2020.100023

Halbe, J., & Pahl-Wostl, C. (2019). A Methodological Framework to Initiate and Design Transition Governance Processes. *Sustainability*, *11*(3), 844. https://doi.org/10.3390/su11030844

Hale, T., & Roger, C. (2014). Orchestration and transnational climate governance. *The Review of International Organizations*, *9*(1), 59–82. https://doi.org/10.1007/s11558-013-9174-0

Harris, S., Weinzettel, J., Bigano, A., & Källmén, A. (2020). Low carbon cities in 2050? GHG emissions of European cities using production-based and consumption-based emission accounting methods. *Journal of Cleaner Production*, *248*. https://doi.org/10.1016/j.jclepro.2019.119206

Hendriks, C. M., & Lees-Marshment, J. (2019). Political Leaders and Public Engagement: The Hidden World of Informal Elite–Citizen Interaction. *Political Studies*, *67*(3), 597–617. https://doi.org/10.1177/0032321718791370

Heo, K., & Seo, Y. (2021). Anticipatory governance for newcomers: Lessons learned from the UK, the Netherlands, Finland, and Korea. *European Journal of Futures Research*, *9*(1), 9. https://doi.org/10.1186/s40309-021-00179-y

Hueston, W., & McLeod, A. (2012). Overview of the Global Food System: Changes over Time/Space and Lessons for Future Food Safety. In *Improving Food Safety Through a One Health Approach: Workshop Summary* (pp. 189–197). National Academies Press (US).

Institute for Global Environment Strategies, Aalto University, & D-mat ltd. (2019). *1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints. Technical Report*. Institute for Global Environmental Strategies, Hayama, Japan.

International Energy Agency. (2019). World Energy Outlook 2019. In *World Energy Outlook 2019*.

International Transport Forum. (2019). *Transport Innovations from the Global South. Case Studies, Insights, Recommendations*. OECD Publishing.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

IPCC. (2019). Summary for Policymakers. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H. O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. Van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, … J. Malle (Eds.), *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Intergovernmental Panel on Climate Change. In Press.

Isman, M., Archambault, M., Racette, P., Konga, C. N., Llaque, R. M., Lin, D., Iha, K., & Ouellet-Plamondon, C. M. (2018). Ecological Footprint assessment for targeting climate change mitigation in cities: A case study of 15 Canadian cities according to census metropolitan areas. *Journal of Cleaner Production*, *174*, 1032–1043. https://doi.org/10.1016/j.jclepro.2017.10.189

ISO. (2014). *Environmental management—Water footprint—Principles, requirements and guidelines (ISO Standard No. 14046:2014)*. International Organization for Standardization. https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/04/32/43263.html

ISO. (2018). *ISO 37120:2018 Sustainable cities and communities—Indicators for city services and quality of life*. International Standard Organization.

Jancovici, J.-M. (2017). *Dormez tranquilles jusqu'en 2100 Et autres malentendus sur le climat et l'énergie*.

Jensen, P. D., & Orfila, C. (2021). Mapping the production-consumption gap of an urban food system: An empirical case study of food security and resilience. *Food Security*. https://doi.org/10.1007/s12571-021-01142-2

Jones, B. (2021, April 12). The hottest number in conservation is rooted more in politics than science. *VOX*.

Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology*, *11*(2), 43–59. https://doi.org/10.1162/jie.2007.1107

Kennedy, C., Pincetl, S., & Bunje, P. (2011). The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*, *159*(8–9), 1965–1973. https://doi.org/10.1016/j.envpol.2010.10.022

Kennedy, C., Stewart, I., Facchini, A., Cersosimo, I., Mele, R., Chen, B., Uda, M., Kansal, A., Chiu, A., Kim, K. G., Dubeux, C., La Rovere, E. L., Cunha, B., Pincetl, S., Keirstead, J., Barles, S., Pusaka, S., Gunawan, J., Adegbile, M., … Sahin, A. D. (2015). Energy and material flows of megacities. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(19), 5985–5990. https://doi.org/10.1073/pnas.1504315112

Kissinger, M., & Rees, W. E. (2010). An interregional ecological approach for modelling sustainability in a globalizing world-Reviewing existing approaches and emerging directions. *Ecological Modelling*, *221*(21), 2615–2623. https://doi.org/10.1016/j.ecolmodel.2010.07.003

Kissinger, M., & Stossel, Z. (2019). Towards an interspatial urban metabolism analysis in an interconnected world. *Ecological Indicators*, *101*, 1077–1085. https://doi.org/10.1016/j.ecolind.2018.11.022

Kitzes, J., Wackernagel, M., Loh, J., Peller, A., Goldfinger, S., Cheng, D., & Tea, K. (2008). Shrink and share: Humanity's present and future Ecological Footprint. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 467–475. https://doi.org/10.1098/rstb.2007.2164

Kübler, D., & Rochat, P. E. (2019). Fragmented Governance and Spatial Equity in Metropolitan Areas: The Role of Intergovernmental Cooperation and Revenue-Sharing. *Urban Affairs Review*, *55*(5), 1247–1279. https://doi.org/10.1177/1078087417753079

LaCanne, C. E., & Lundgren, J. G. (2018). Regenerative agriculture: Merging farming and natural resource conservation profitably. *PeerJ*, *2018*(2). https://doi.org/10.7717/peerj.4428

Länderarbeitskreis Energiebilanzen. (n.d.-a). *Methodik der CO2-Bilanzen*.

Länderarbeitskreis Energiebilanzen. (n.d.-b). *Verursacherbilanz: CO2-Emissionen nach Emittentensektoren*.

Landry, V., Asselin, H., & Lévesque, C. (2019). Link to the land and Mino-pimatisiwin (comprehensive health) of indigenous people living in urban areas in Eastern Canada. *International Journal of Environmental Research and Public Health*, *16*(23). https://doi.org/10.3390/ijerph16234782

Le Quéré, C., Peters, G. P., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Davis, S. J., Jackson, R. B., & Jones, M. W. (2021). Fossil CO2 emissions in the post-COVID-19 era. *Nature Climate Change*, *11*, 197–199. https://doi.org/10.1038/s41558-021-01001-0

Levitt, C. J., Saaby, M., & Sørensen, A. (2019). The impact of China's trade liberalisation on the greenhouse gas emissions of WTO countries. *China Economic Review*, *54*, 113–134. https://doi.org/10.1016/j.chieco.2018.10.012

Lewis, S. L., & Maslin, M. A. (2015). Defining the Anthropocene. *Nature*, *519*(7542), 171–180. https://doi.org/10.1038/nature14258

Li, M., Wiedmann, T., Liu, J., Wang, Y., Hu, Y., Zhang, Z., & Hadjikakou, M. (2020). Exploring consumption-based planetary boundary indicators: An absolute water footprinting assessment of Chinese provinces and cities. *Water Research*, *184*. https://doi.org/10.1016/j.watres.2020.116163

Lieber, J. (2018). *Urban Ecology: A Bright Future for Sustainable Cities*. The Revelator - An Initiative of the Center for Biological Diversity. https://therevelator.org/urban-ecology-sustainable-cities/

Liu, Z., Ren, Y., Shen, L., Liao, X., Wei, X., & Wang, J. (2020). Analysis on the effectiveness of indicators for evaluating urban carrying capacity: A popularity-suitability perspective. *Journal of Cleaner Production*, *246*. https://doi.org/10.1016/j.jclepro.2019.119019

Lombardi, M., Laiola, E., Tricase, C., & Rana, R. (2017). Assessing the urban carbon footprint: An overview. *Environmental Impact Assessment Review*, *66*, 43–52. https://doi.org/10.1016/j.eiar.2017.06.005

Ma, P., Ye, G., Peng, X., Liu, J., Qi, J., & Jia, S. (2017). Development of an index system for evaluation of ecological carrying capacity of marine ecosystems. *Ocean & Coastal Management*, *144*, 23–30. https://doi.org/10.1016/j.ocecoaman.2017.04.012

MacDonald, A., Clarke, A., Huang, L., Roseland, M., & Seitanidi, M. M. (2018). Multi-stakeholder Partnerships (SDG #17) as a Means of Achieving Sustainable Communities and Cities (SDG #11). *World Sustainability Series*, 193–209. https://doi.org/10.1007/978-3-319-63007-6_12

Mang, P., & Reed, B. (2019). Regenerative Development and Design. *Encyclopedia of Sustainability Science and Technology*, 1–28. https://doi.org/10.1007/978-1-4939-2493-6_303-4

Marris, E. (2019). To keep the planet flourishing, 30% of Earth needs protection by 2030. *National Geographic \ Environment \ News*.

Mathis, K. (2018). Sustainability Strategies and the Problem of the Rebound Effect. *Energy Law and Economics*, 3–17. https://doi.org/10.1007/978-3-319-74636-4_1

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. I. (1972). *The Limits to Growth. A report to the Club of Rome's project on the predicament of mankind*.

Metro Vancouver. (2013). *2010 Lower Fraser Valley Air Emissions Inventory and Forecast and Backcast*. http://www.metrovancouver.org/services/air-quality/AirQualityPublications/2010LowerFraserValleyAirEmissionsInventoryandForecastandBackcast.pdf

Millennium Ecosystem Assessment. (2005). Millennium Ecosystem Assessment: Ecosystems and Human Well-being, Synthesis report. In *Island press*. https://doi.org/10.1196/annals.1439.003

Mirabella, N., & Allacker, K. (2021). Urban GHG accounting: Discrepancies, constraints and opportunities. *Buildings and Cities*, *2*(1), 21–35. https://doi.org/10.5334/bc.50

MNAI. (n.d.). *Municipal Asset Management Initiative*. Retrieved December 15, 2020, from https://mnai.ca/

MNAI. (2020). *Cohort 2: National Project Overview Summary Reports*. Municipal Natural Assets Initiative.

Moore, J. (2015). Ecological footprints and lifestyle archetypes: Exploring dimensions of consumption and the transformation needed to achieve urban sustainability. *Sustainability (Switzerland)*, *7*(4), 4747–4763. https://doi.org/10.3390/su7044747

Moore, J., Kissinger, M., & Rees, W. E. (2013). An urban metabolism and ecological footprint assessment of Metro Vancouver. *Journal of Environmental Management*, *124*, 51–61. https://doi.org/10.1016/j.jenvman.2013.03.009

Moore, J., Miller, K., Register, R., Campbell, S., & Eberlein, S. (2019). *International Ecocity Standards (brochure)*. Ecocuty Builders.

Moore, J., & Rees, W. E. (2013). Getting to One-Planet Living. In Worldwatch Institute (Ed.), *State of the World 2013*. Island Press.

Moran, D., Kanemoto, K., Jiborn, M., Wood, R., Többen, J., & Seto, K. C. (2018). Carbon footprints of 13 000 cities. *Environmental Research Letters*, *13*(6). https://doi.org/10.1088/1748-9326/aac72a

Nagendra, H., Bai, X., Brondizio, E. S., & Lwasa, S. (2018). The urban south and the predicament of global sustainability. *Nature Sustainability*, *1*(7), 341–349. https://doi.org/10.1038/s41893-018-0101-5

Öjendal, J., & Dellnas, A. (2010). Governance Dilemmas of Sustainable Cities. *ICLD Working Paper*, *1*.

O'Neill, D. W., Fanning, A. L., Lamb, W. F., & Steinberger, J. K. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, *1*(2), 88–95. https://doi.org/10.1038/s41893-018-0021-4

Ortega-Montoya, C. Y., & Johari, A. (2020). Urban Ecological Footprints. In W. L. Filho, A. M. Azul, L. Brandli, P. G. Özuyar, & T. Wall (Eds.), *Sustainable Cities and Communities*. Springer International Publishing.

Palumbo, R. (2017). Participatory Governance. In A. Farazmand (Ed.), *Global Encyclopedia of Public Administration, Public Policy, and Governance* (pp. 1–6). Springer International Publishing. https://doi.org/10.1007/978-3-319-31816-5_1834-1

Paterson, W., Rushforth, R., Ruddell, B. L., Konar, M., Ahams, I. C., Gironás, J., Mijic, A., & Mejia, A. (2015). Water footprint of cities: A review and suggestions for future research. *Sustainability (Switzerland)*, *7*(7), 8461–8490. https://doi.org/10.3390/su7078461

Patterson, T. M., & Coelho, D. L. (2009). Ecosystem services: Foundations, opportunities, and challenges for the forest products sector. *Forest Ecology and Management*, *257*(8), 1637–1646. https://doi.org/10.1016/j.foreco.2008.11.010

Peng, J., Du, Y., Liu, Y., & Hu, X. (2016). How to assess urban development potential in mountain areas? An approach of ecological carrying capacity in the view of coupled human and natural systems. *Ecological Indicators*, *60*, 1017–1030. https://doi.org/10.1016/j.ecolind.2015.09.008

Pham, T. T. H., Apparicio, P., Landry, S., & Lewnard, J. (2017). Disentangling the effects of urban form and socio-demographic context on street tree cover: A multi-level analysis from Montréal. *Landscape and Urban Planning*, *157*, 422–433. https://doi.org/10.1016/j.landurbplan.2016.09.001

Raworth, K. (2017). A Doughnut for the Anthropocene: Humanity's compass in the 21st century. *The Lancet Planetary Health*, *1*(2), e48–e49. https://doi.org/10.1016/S2542-5196(17)30028-1

Rees, W. E. (2012). Cities as Dissipative Structures: Global Change and the Vulnerability of Urban Civilization. In *Sustainability Science: The Emerging Paradigm and the Urban Environment*. Springer. https://doi.org/10.1007/978-1-4614-3188-6

Rees, W. E. (2013). Ecological Footprint, Concept of. *Encyclopedia of Biodiversity (Second Edition)*, 701–713.

Rees, W. E. (2020). Ecological economics for humanity's plague phase. *Ecological Economics*, *169*. https://doi.org/10.1016/j.ecolecon.2019.106519

Ripple, W., Wolf, C., Galetti, M., Newsome, T., Alamgir, M., Crist, E., & 15364 scientist signatories from 184 countries. (2017). World scientists' warning to humanity: A second notice. *BioScience*, *67*(12), 1026–1028.

Ritchie, H. (2019). *Half of the world's habitable land is used for agriculture*. https://ourworldindata.org/global-land-for-agriculture

Ritchie, H., & Roser, M. (2020). *Environmental impacts of food production*. https://ourworldindata.org/environmental-impacts-of-food

Robinson, J., & Cole, R. J. (2015). Theoretical underpinnings of regenerative sustainability. *Building Research and Information*, *43*(2), 133–143. https://doi.org/10.1080/09613218.2014.979082

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Joachim, H. (2017). *A roadmap for rapid decarbonization*. *355*(6331). https://doi.org/10.1126/science.aah3443

Rockström, J., Steffen, W., Noone, K., Chapin, F. S. I., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Correll, R. W., Fabry, V. J., Hansen, J., Walker, B., … Foley, J. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society*, *14*(2), 32. https://doi.org/10.1007/s13398-014-0173-7.2

Rodale Institute. (2014). *Regenerative Organic Agriculture and Climate Change (white paper)*.

Sala, S., Ciuffo, B., & Nijkamp, P. (2015). A systemic framework for sustainability assessment. *Ecological Economics*, *119*, 314–325. https://doi.org/10.1016/j.ecolecon.2015.09.015

Science for Environment Policy. (2018). *Indicators for sustainable cities. In-depth Report 12*. Produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol.

Shorrocks, A., Davies, J., & Lluberas, R. (2020). *Global wealth report 2020*.

Slack, E., & Côté, A. (2014). *Comparative urban governance* (p. 60). Foresight, Government Office for Science.

Solow, R. M. (1993). An almost practical step toward sustainability. *Resources Policy*, *19*(3), 162–172. https://doi.org/10.1016/0301-4207(93)90001-4

Spiliotopoulou, M. (2021). *Sustainable Community Development through the conceptual lens of productivity (Unpublished doctoral dissertation)*. Simon Fraser University.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), 1259855-. https://doi.org/10.1126/science.1259855

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., Summerhayes, C. P., Barnosky, A. D., Cornell, S. E., Crucifix, M., Donges, J. F., Fetzer, I., Lade, S. J., Scheffer, M., Winkelmann, R., & Schellnhuber, H. J. (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*, *115*(33), 8252–8259. https://doi.org/10.1073/pnas.1810141115

Stein, A. (2018). *Climatic impact of residential buildings. An Examination of Greenhouse Gas Emissions in the Residential Building Sector, Factors that influence Energy Use and the Energy Saving Potentials analysed for the Borough Altona in Hamburg*. HafenCity Universität Hamburg.

Świąder, M. (2018). The implementation of the concept of environmental carrying capacity into spatial management of cities: A review. *Management of Environmental Quality: An International Journal*, *29*(6), 1059–1074. https://doi.org/10.1108/MEQ-03-2018-0049

Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J. K., Ramaswami, A., Robinson, B., Salat, S., Suh, S., Currie, P., Fang, A., Hanson, A., Kruit, K., Reiner, M., Smit, S., & Tabory, S. (2018). *The weight of cities: Resource requirements of future urbanization*.

Tainter, J. A., & Taylor, T. G. (2014). Complexity, problem-solving, sustainability and resilience. *Building Research and Information*, *42*(2), 168–181. https://doi.org/10.1080/09613218.2014.850599

The British Standards Institution. (2014). *Application of PAS 2070 – London, United Kingdom: An assessment of greenhouse gas emissions of a city*.

Tigre, M. A. (2015). From Ideas to Implementation: Creating Sustainable Cities with Good Governance How to Think about Governance innovation Integrated Transport mass. *The City Fix*. https://thecityfix.com/blog/ideas-implementation-creating-sustainable-cities-good-governance-maria-antonia-tigre/

UNEP. (2020). *Emissions Gap Report 2020*.

United Nations. (2015). *Resolution 70/1. Transforming our world: The 2030 Agenda for Sustainable Development*.

United Nations. (2019). *World Population Prospects 2019: Ten Key Findings*. Department of Economic and Social Affairs, & Population Division.

van der Heijden, J. (2019). Studying urban climate governance: Where to begin, what to look for, and how to make a meaningful contribution to scholarship and practice. *Earth System Governance*, *1*, 100005. https://doi.org/10.1016/j.esg.2019.100005

van Neuss, L. (2018). Globalization and deindustrialization in advanced countries. *Structural Change and Economic Dynamics*, *45*, 49–63. https://doi.org/10.1016/j.strueco.2018.02.002

Vigier, M., Moore, J., & Ouellet-Plamondon, C. (2021). How to identify cities on the path towards real sutainability? *[Manuscript Submitted for Publication]*.

Vodden, K., Hunt, L., & Bell, R. (2016). Evolving Conceptions of the Social Economy: The Arts, Culture, and Tourism in Alert Bay. In M. Gismondi, S. Connelly, M. Beckie, S. Markey, & M. Roseland (Eds.), *Scaling up: The convergence of social economy and sustainability*. Athabasca University Press.

von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C., & Stasinopoulos, P. (2009). Chapter 1—A Framework for Factor Five—The Natural Edge Project. In *Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity—A Report to the Club of Rome*. Earthscan Publications Ltd.

Wackernagel, M., Halle, M., & Scott, M. (2013). *Atlas de l'Empreinte Écologique et de la Biocapacité Des Pays Membres De La Francophonie*. 101.

Wackernagel, M., & Rees, W. E. (1996). Our Ecological Footprint. In *New Society Publishers*. New Society Publishers.

Wahl, D. C. (2016). *Designing Regenerative Cultures*. Triarchy Press.

Ward, M., Saura, S., Williams, B., Ramírez-Delgado, J. P., Arafeh-Dalmau, N., Allan, J. R., Venter, O., Dubois, G., & Watson, J. E. M. (2020). Just ten percent of the global terrestrial protected area network is structurally connected via intact land. *Nature Communications*, *11*(1). https://doi.org/10.1038/s41467-020-18457-x

Waridel, L. (2019). *La transition, c'est maintenant: Choisir aujourd'hui ce que sera demain*. Ecosociété.

Wei, Y., Huang, C., Lam, P., Sha, Y., & Feng, Y. (2015). Using Urban-Carrying Capacity as a Benchmark for Sustainable Urban Development: An Empirical Study of Beijing. *Sustainability*, *7*(3), 3244–3268. https://doi.org/10.3390/su7033244

Wiedmann, T., Chen, G., Owen, A., Lenzen, M., Doust, M., Barrett, J., & Steele, K. (2020). Three-scope carbon emission inventories of global cities. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.13063

Wiedmann, T., & Minx, J. (2007). A Definition of ' Carbon Footprint. *Science*, *1*(01), 1–11.

Williams, C. C., & Millington, A. C. (2004). The Diverse and Contested Meanings of Sustainable Development. *The Geographical Journal*, *170*(2), 99–104. https://doi.org/10.2307/3451586

Williams, J. J. (2006). Community Participation: Lessons from South Africa. *Policy Studies*, *27*(3). https://doi.org/10.1080/01442870600885982

Wilmsen, F., & Gesing, F. (2016). The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) – A New Passage Point on an Old Road? *ZenTra Working Paper in Transnational Studies*, *68/2016*.

Wolfram, M. (2016). Conceptualizing urban transformative capacity: A framework for research and policy. *Cities*, *51*, 121–130. https://doi.org/10.1016/j.cities.2015.11.011

World Population Review. (n.d.). *World City Populations 2021*. World Population Review.

World Resources Institute, C40 Cities, & ICLEI - Local Governments for Sustainability. (2014). *Greenhouse Gas Protocol. Global Protocol for Community—Scale Greenhouse Gas Emissions Inventories*.

Appendices

Appendix A: Glossary

Anticipatory Governance: is defined a system based on foresights to anticipate incoming emerging challenges and trends and evaluate the implications and further impacts of public policies (Heo & Seo, 2021). Anticipatory governance represents a sustainable decision-making process relying on collaborative participation of different stakeholders such as governments, academics or public sector towards a consensual desirable future.

Climate Governance: aims at mitigating global carbon emissions and managing the impacts of climate change through local, regional, or international levels of decision-making (González & Numer, 2020). Among these various initiatives are networks of cities working at reducing their footprint, voluntary corporate reduction objectives, and other rules governing the carbon market (Hale & Roger, 2014).

Earth Carrying Capacity: represents the biophysical limits of Earth, or the maximum anthropic pressure that our planet can sustain without engaging irreversible changes (Casey, 2021; O'Neill et al., 2018). It is generally measured by the total available resources of Earth or its global biocapacity (Moore & Rees, 2013).

Earth System Governance: is a research framework that was launched in 2009 by a group of global change researchers and was endorsed by the International Human Dimensions Programme on Global Environmental Change (IHDP) (Biermann et al., 2010). Earth system governance reflects on political solutions and alternative effective governance mechanisms to face the current changes in the various ecosystems of our planet (Burch et al., 2019). This framework coordinates around five main challenges identified as the five "A"s (accountability, adaptiveness, agency, allocation and access, and architecture) evolving around crosscutting themes, regulations, power and scales.

Ecological Carrying Capacity: assesses the anthropic pressure the natural capital of a specific ecosystem can withstand, in a context of resources depletion, ecological destruction and environmental (Ma et al., 2017; Peng et al., 2016). Its core focus has evolved from the growth law of biotic population to the challenge of sustaining human enterprise (Ma et al., 2017).

Environmental Carrying Capacity: defines the population that can be sustained in a steady state in a specific area, considering its relative pressure on the environment and the capacity of the latter to balance and withstand without triggering irreversible changes (Świąder, 2018).

Good Governance: is the combination of a governing model and the informal social elements that enable a city to function in a way that allows policies to be implemented through mechanisms that are considered to be socially just, fair and equitable (Biermann et al., 2014). It encompasses inclusive values such as transparency, accountability, and public access to information.

Participatory Governance: refers to democratic mechanism aimed at empowering citizen by making them agent of change for the city through urban collaborative management and decision-making (Palumbo, 2017). It bridges the gap between public institutions, local businesses and city dwellers by giving them deliberative power to further increase effectiveness of public policies.

Smart City Governance: corresponds to the definition and implementation of urban policies and the management of different infrastructures and initiatives aimed at making the various dimensions of a city

smarter (Castelnovo et al., 2016). It encompasses the development of technological infrastructures such as information and communication technologies (ICTs) infrastructures and systems, the management of financial resources and human assets to support the sustainability of smart cities over time, along with other immaterial aspects (social and relational capital, intellectual property and innovation, and knowledge and information) that are indispensable for smart sustainable growth (Batagan, 2011). Smart City Governance seeks to reconcile with optimization of resources management, the reach of economic sustainability and the achievement of inclusiveness and social equity of its citizen (Castelnovo et al., 2016).

Sustainable Governance: is a concept based on resource management and inclusive considerations regarding marginalized indigenous groups and community participation to bring local knowledge and practices to achieve sustainability (Billi et al., 2021). These sets of values aim at promoting a sustainable future for the generations to come.

Transformative Governance: is a type of environmental governance whose aim is to shift current deteriorated social-ecological systems (SESs) to alternative, preferable, more functional regimes by transforming the structures and processes defining the system (Chaffin et al., 2016). Transformative governance further focuses on different aspects aimed at supporting social-ecological paradigms, such as increased risk tolerance, significant systemic investment, and restructured economies and power relations.

Transition Management/Transition Governance: aims at steering societal transformation towards sustainability through reflexive governance by embracing the multi-actor processes encompassed in our societies (Halbe & Pahl-Wostl, 2019). Transition governance relies on various strategies such as transdisciplinary knowledge development, adaptivity strategies and institutions, anticipation of long-term impact of the measures, participatory and iterative goal formulation or interactive strategy-development.

Urban Carrying Capacity: determines the level of sustainability of an urban area based not only on ecology aspects or physical infrastructure, but also on the economic, social, environmental and institutional aspects of the regions (Wei et al., 2015). It can be subdivided in different categories such as environmental impacts and natural resources; infrastructure and urban services, public perception; institution setting; and society supporting capacity.

Urban Governance: refers to the process through which democratically elected local governments and the range of stakeholders in cities – such as business associations, unions, civil society and, of course, citizens – make decisions about how to plan, finance, and manage the urban realm. It has an impact on the quantity and quality of local public services and the efficiency with which they are delivered. It determines whether costs are shared throughout the city-region in a fair and efficient way. Urban governance also affects the ability of residents to access their local government and engage in local decision-making, as well as the extent to which local governments are accountable to citizens and responsive to their demands (Slack & Côté, 2014).

Appendix B: Sustainability Frameworks

Table B-1. *Sustainability frameworks identified: their level of coverage of all five domains of consumption and their level of alignment with the goal of operating within Earth's carrying capacity.*

Name of Framework	Coverage of all five domains of consumption		Alignment with goal of living within Earth's carrying capacity	
	Full	**Partial**	**Full**	**Partial**
AICHI Targets	Inadequate information		Inadequate information	
ASEAN SDGs Frontrunner Cities Programme		✓		✓
ASEAN Sustainable Urbanization Strategy (ASUS)		✓	Inadequate information	
Audubon International Sustainable Communities Program		✓	Inadequate information	
BREEAM Communities		✓	✓	
C40 Climate Action Planning Framework		✓	✓	
C40 Thriving Cities	✓		✓	
Circular Economy	✓		✓	
Doughnut Economics	✓		Inadequate information	
Eco2 cities (Ecological cities as economic cities)		✓	✓	
Ecocity Standards	✓		✓	
EcoDistricts		✓	✓	
EU Reference Framework for Sustainable Cities		✓		✓
Global City Indicators Program	Inadequate information		Inadequate information	
Global Footprint Network	✓		✓	
Global Sustainability Assessment System		✓	✓	
ISO 37120		✓	✓	
LEED Cities v4.1		✓	✓	
Living Cities Challenge	✓		✓	
Low Carbon City		✓	✓	
One Planet Living Cities	✓		✓	
Pearl Community Rating System		✓	✓	
Planetary Boundaries	✓		✓	
Resilient Cities Network		✓	✓	
Resources and Energy Analysis Programme (REAP)		✓	Inadequate information	
SDGs Future City		✓	Inadequate information	
Smart City		✓		✓
Sustainable Development Goals (SDGs)		✓		✓
SymbioCity Approach (SCA)		✓	✓	
The Natural Step	✓		✓	
Transition Network	✓		✓	
Urban Low Emission Development		✓	Inadequate information	
Urban metabolism	✓		✓	

Table B-2. *Metrics used to measure living within the Earth Carrying capacity, in three categories.*

Climate based	Ecological footprint	Energy and material flow analysis
Greenhouse gas emissions, in metric ton of CO_2e/capita; Metric ton of CO_2/km^2; Metric ton of CO_2/$; Carbon emissions, travel (kg CO_2e/person/yr); GHG emissions residential buildings (kg CO_2e/person/year and kg CO_2e/m2/year); GHG emissions non-residential buildings (kg CO_2e/m^2/year);	gha/capita; Carbon footprint per capita; EF / GDP ; Ecological footprint diversity	Total end-use energy consumption per capita (GJ/year); Final energy consumption of public buildings per year (GJ/m^2); Electricity consumption of public street lighting per kilometer of lighted streets (kWh/year); Energy consumption in TJ; kg/year; kg/capita/year; kt /capita; Water consumption in litres/person/year; Landfill waste in tonnes/person/year; Hazardous waste in tonnes/capita; Material flows of products and services through an area, in thousands of tonnes; Building materials in kg/m^2 or mt; Building materials in kg/m^2 or mt; Food in $/capita; Food in Kcal/capita/year; Food in kg/capita/year; Waste in USD/kg (GDP/waste)

Table B-3. *Cities studied in urban metabolism literature, by geographical location.*

Per region	Number	City(ies)	Sources	
World	100+	100+ cities	51	61
North America	1	Los Angeles	56	
South America	3	Sao Paulo, Buenos Aires, Rio de Janeiro,	56	
Europe	10 +	Rennes, Le Mans, Brussels, Paris, Lisbon, Madrid, London, Manchester, other European cities (e.g. in Austria and Spain)	48 50 51 52 53	55 56 60 61
Asia	11 +	Beijing, Delhi, Dhaka, Guangzhou, Istanbul, Karachi, Manila, Seoul, Shenzhen, Kinmen island, Shenyang, other Chinese cities	51 53 54 56	58 59 61
Africa	2	Cape Town, Cairo	49	56
Oceania	1	Melbourne	56	

Note: the source numbers refer to items in the Annotated Bibliography for Theme 1 (Appendix D)

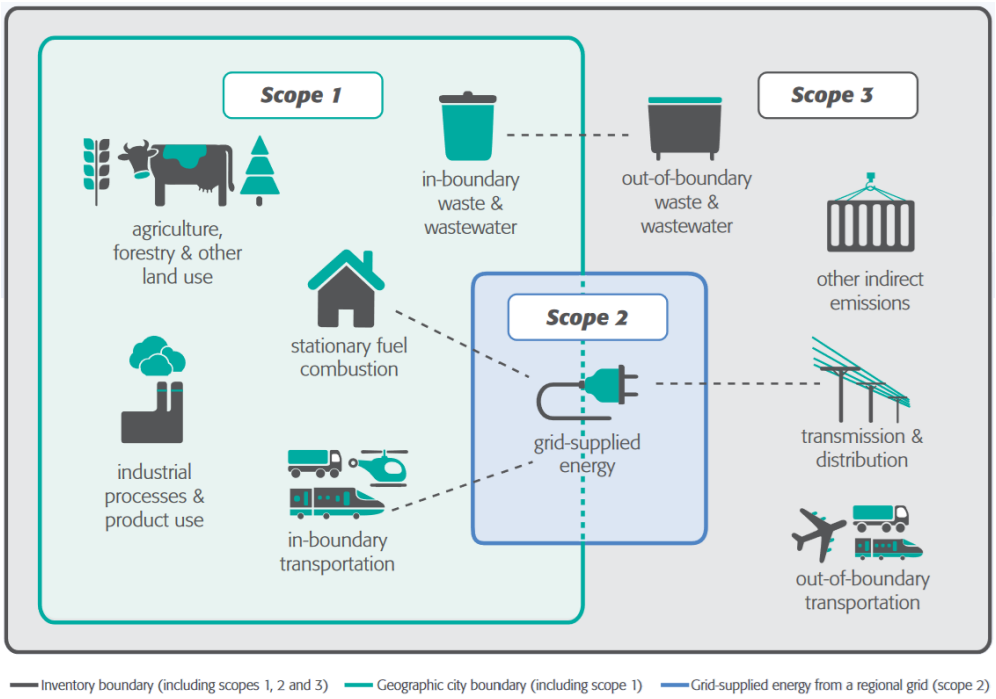

Figure B-1. *Sources and boundaries for the accounting Scopes.*

Source: Greenhouse Gas Protocol (World Resources Institute, 2014).

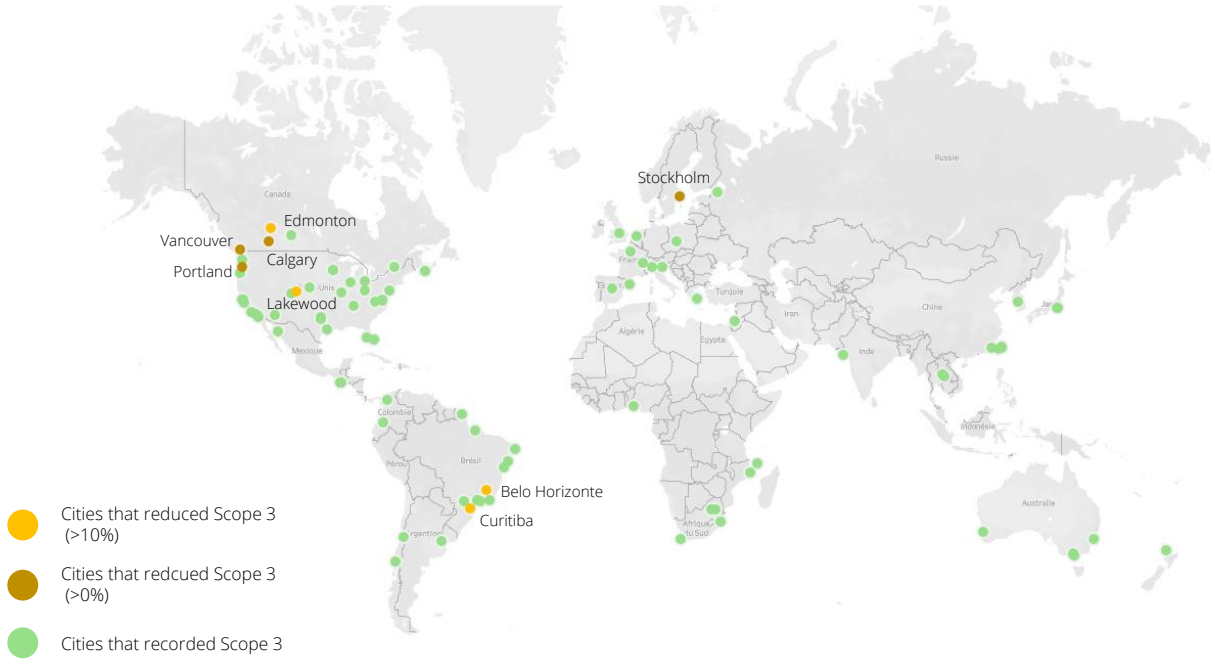

Figure B-2. *Cities reporting and reducing their Scope 3.*

Note: based on Carbon Disclosure Project, City-Wide Emissions data sets 2018 – 2019, retrieved from https://data.cdp.net/browse?category=Emissions .

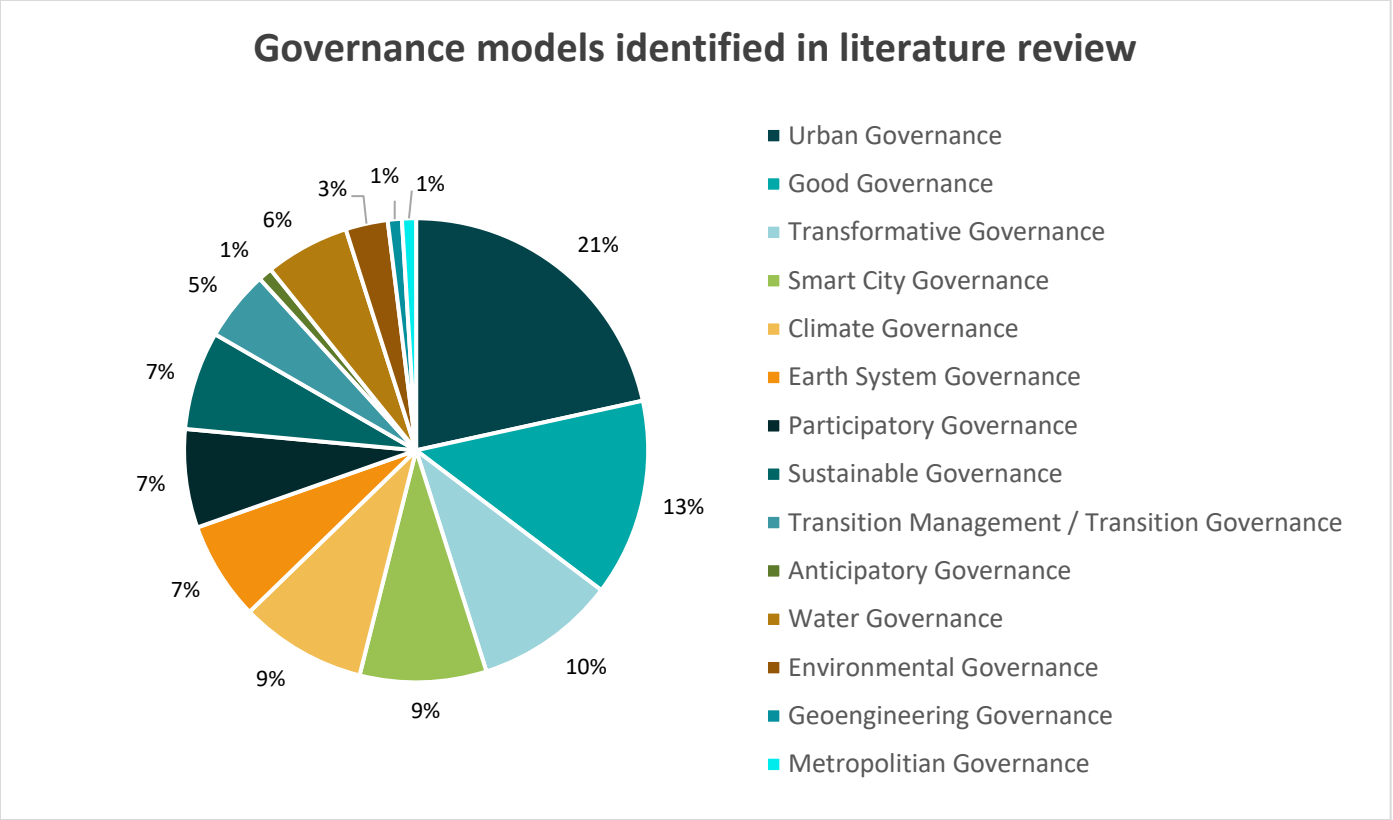

Figure B-3. *Governance models Identified in the review of the related literature.*

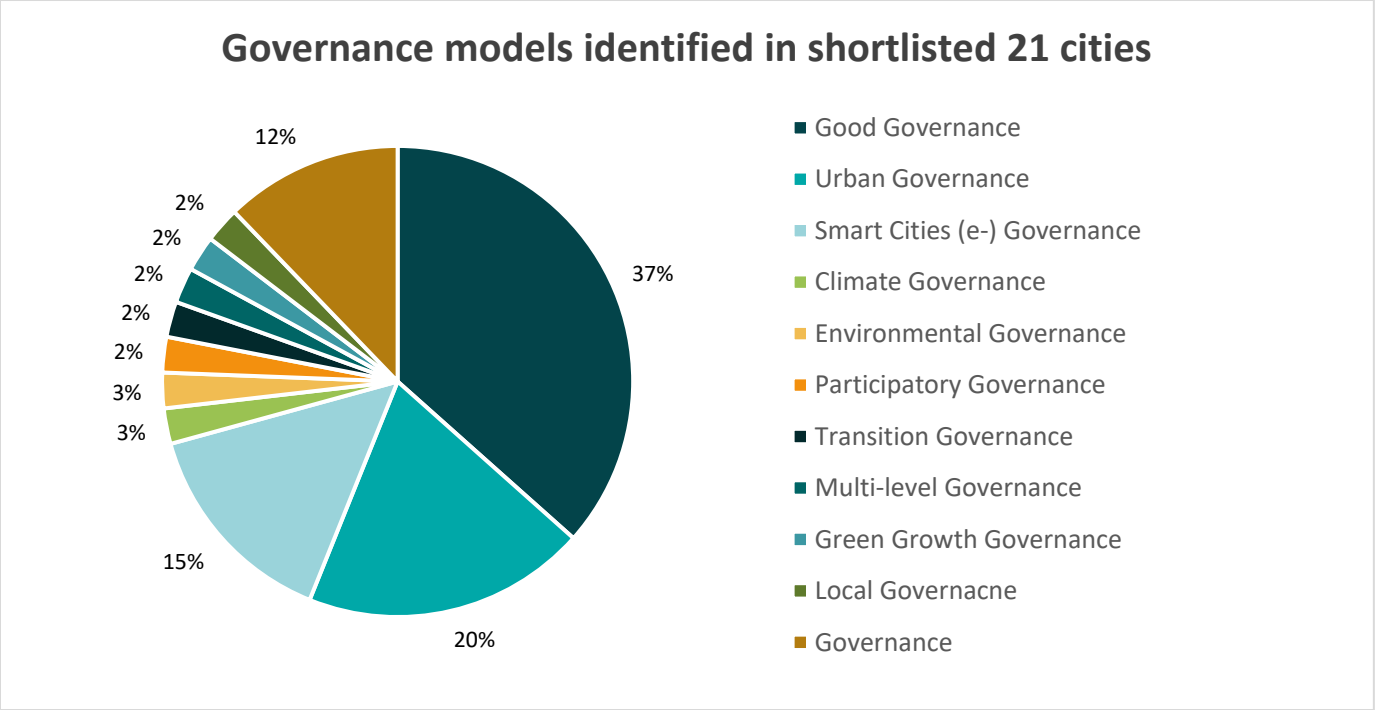

Figure B-4. *Governance models identified in the 21 shortlisted cities.*

Table B-4. *Cities reducing their ecological footprint on an absolute or normalized basis (2010-2020).*

								Per capita		Absolute	
Cities	baseline year	gha/ca	Population baseline	final year	gha/ca	Population final	Variation in population	gha/ca	(%)	gha	(%)
Alexandria	2010	2.53	4332570	2015	2.5	4789632	10.5%	-0.03	-1.19%	-1012677.9	-9.24%
Antalya	2010	2.7	896772	2015	2.65	1083923	20.9%	-0.05	-1.85%	451112.669	18.63%
Athens	2010	4.84	4019593	2015	4.89	3161155	-21.4%	0.05	1.03%	-3996779.8	-20.54%
Barcelona	2010	4.52	4721271	2015	4.52	5276919	11.8%	0	0.00%	2511527.41	11.77%
Cairo	2010	2.85	12835255	2015	2.82	18820072	46.6%	-0.03	-1.05%	16492127.1	45.08%
Calgary	2010	10.02	1190362	2015	9.43	1360316	14.3%	-0.59	-5.89%	900352.64	7.55%
Charlottetown	2010	3.87	41613	2015	3.83	44739	7.5%	-0.04	-1.03%	10308.06	6.40%
Edmonton	2010	8.26	1137346	2015	8.61	1292151	13.6%	0.35	4.24%	1730942.15	18.43%
Genoa	2010	4.89	904919	2015	4.81	692425	-23.5%	-0.08	-1.64%	-1094491.3	-24.73%
Halifax	2010	7.46	387265	2015	7.15	401115	3.6%	-0.31	-4.16%	-21024.65	-0.73%
Istanbul	2010	3.23	13017265	2015	3.17	14126772	8.5%	-0.06	-1.86%	2736100.9	6.51%
Izmir	2010	2.94	2812838	2015	2.96	2860197	1.7%	0.02	0.68%	196439.729	2.38%
Marseille	2010	4.72	1643012	2015	4.71	1587434	-3.4%	-0.01	-0.21%	-278202.81	-3.59%
Montréal	2010	4.22	1649519	2015	4.18	1704694	3.3%	-0.04	-0.95%	164650.74	2.37%
Naples	2010	3.34	4399644	2015	3.39	4394563	-0.1%	0.05	1.50%	202756.732	1.38%
Ottawa	2010	4.48	883391	2015	4.99	934243	5.8%	0.51	11.38%	704280.89	17.80%
Palermo	2010	3.83	960129	2015	3.76	854385	-11.0%	-0.07	-1.83%	-464807.9	-12.64%
Québec City	2010	4.37	519949	2015	4.33	531902	2.3%	-0.04	-0.92%	30958.53	1.36%
Regina	2010	7.4	193100	2015	7.39	215106	11.4%	-0.01	-0.14%	160693.34	11.25%
Rome	2010	4.7	4172591	2015	4.63	4113185	-1.4%	-0.07	-1.49%	-567129.91	-2.89%
Saint John	2010	6.06	70063	2015	5.31	67575	-3.6%	-0.75	-12.38%	-65758.53	-15.49%
Saskatoon	2010	7.26	222189	2015	7.07	246376	10.9%	-0.19	-2.62%	128786.18	7.98%
Shanghai	2012	3.9	21555452	2016	3.63	24163230	12.1%	-0.27	-6.92%	3646262.1	4.34%

Cities	baseline year	gha/ca	Population baseline	final year	gha/ca	Population final	Variation in population	Per capita		Absolute	
								gha/ca	(%)	gha	(%)
St John's	2010	4.46	106172	2015	4.86	108860	2.5%	0.4	8.97%	55532.48	11.73%
Tel Aviv	2010	4,06	3310530	2015	4,04	3702758	11,8%	-0,02	-0,49%	1518390,52	11,30%
Thessaloniki	2010	4.25	1154856	2015	4.17	809043	-29.9%	-0.08	-1.88%	-1534428.6	-31.26%
Tirana	2010	2.11	729009	2015	2.08	449298	-38.4%	-0.03	-1.42%	-603669.18	-39.24%
Tokyo	2011	4.5	36975440	2013	5.24	37185744	0.6%	0.74	16.44%	28463818.56	17.11%
Toronto	2010	4.19	2615060	2015	4.08	2731571	4.5%	-0.11	-2.63%	187708.28	1.71%
Tunis	2010	3.12	1915961	2015	3.12	2182869	13.9%	0	0.00%	832752.96	13.93%
Valencia	2010	4.04	1852376	2015	4.07	812636	-56.1%	0.03	0.74%	-4176172.5	-55.80%
Valletta	2010	5.32	80320	2015	5.43	81368	1.3%	0.11	2.07%	14524.8467	3.40%
Vancouver	2010	4.53	603502	2015	4.34	631486	4.6%	-0.19	-4.19%	6785.18	0.25%
Venice	2010	4.02	843639	2015	4.01	629000	-25.4%	-0.01	-0.25%	-869138.38	-25.63%
Victoria	2010	4.55	80017	2015	4.51	85792	7.2%	-0.04	-0.88%	22844.57	6.27%
Winnipeg	2010	4.57	663617	2015	4.22	705224	6.3%	-0.35	-7.66%	-56684.41	-1.87%
Xiamen	2010	1.9	3040000	2012	2.12	3215000	5.8%	0.22	11.58%	1039800	18.00%

Notes:
Negative figures in the "Per capita" and "Absolute" columns signify reductions in ecological footprint between the baseline and final years.
Figures in the "Per capita" column highlighted in blue are reductions; figures in the "Absolute" column highlighted in red indicate increases in ecological footprint over the time period.

Table B-5. *Alternative pathway initiatives around the world.*

Initiative / Sector	Place	Links
Biophilic Cities Network	Worldwide	https://www.biophiliccities.org/partner-cities
Regenerative agriculture practices	Worldwide	https://regenerationinternational.org/regenerative-farm-map
Map of ecologically regenerative projects	Worldwide	https://regen.earth
Turning urban industrial zones into green enclaves	Austin (TX), US	https://www.nationalgeographic.com/environment/urban-expeditions/austin/austin-green-buildings-fight-urban-sprawl/
Paris builds a zero-carbon future with a social conscience	Paris, France	https://news.trust.org/item/20181002005848-vsipf/ & https://www.ademe.fr/sites/default/files/assets/documents/ademe-fiche-zac-clichy-batignolles-uk_web.pdf
Nature-based solutions and transportation initiatives	Medellín, Colombia	https://www.unenvironment.org/news-and-stories/story/medellin-shows-how-nature-based-solutions-can-keep-people-and-planet-cool & https://www.devex.com/news/what-makes-medellin-the-poster-child-of-sustainable-transport-89714
Cheong Gye Cheon Restoration Project	Seoul, South Korea	https://seoulsolution.kr/sites/default/files/policy/[EN]Cheong Gye Cheon Restoration Project.pdf
Fix-It Fairs	Eugene (OR), US	https://www.eugene-or.gov/3581/Fix-It-Fairs
Vermont's Farm to Plate Initiative	Vermont, US	https://www.vtfarmtoplate.com/
Urban mountains: Shenzhen's green rooftop project	Shenzhen, China	www.theguardian.com/cities/gallery/2018/nov/07/urban-mountains-shenzhens-green-rooftop-project-in-pictures
Community participation for San Fernando's zero waste policy	San Fernando, Philippines	https://www.downtoearth.org.in/news/waste/ten-zero-waste-cities-community-participation-worked-wonders-for-san-fernando-67820
Bosco Verticale (Vertical Forest), Milan	Milano, Italy	https://www.greenroofs.com/projects/bosco-verticale-vertical-forest-milan/
Housing First: eradicating homelessness in Finland	Finland	www.centreforpublicimpact.org/case-study/eradicating-homelessness-finland-housing-first-programme/
Emscher Landscape Park: regional park system developed in formerly industrial lands	Ruhr, Germany	https://climate-adapt.eea.europa.eu/metadata/case-studies/a-flood-and-heat-proof-green-emscher-valley-germany/11305605.pdf
Central Innovation District	The Hague, the Netherlands	https://www.denhaag.nl/en/general/central-innovation-district-cid-economic-heart-of-the-hague.htm
Las Salinas: An Ecological and Urban Regeneration	Viña del Mar, Chile	http://designawards.architects.org/projects/campus-and-urban-planning/las-salinas-an-ecological-and-urban-regeneration-in-vina-del-mar-chile/
Europe's first "Sharing City"	Amsterdam, the Netherlands	https://www.sharenl.nl/amsterdam-sharing-city
Social innovation and sharing initiatives	Vancouver, Canada	www.terracycle.com/en-CA, http://thethingery.com, www.woodshop.coop, vancouvertoollibrary.com, www.makerlabs.com, www.eastvankickstand.org
Sunset Park Materials Recovery Facility	New York City, US	https://www.simsmunicipal.com/locations/sunset-park-mrf/

Source: Spiliotopoulou, 2021.

Table B-6. *Type of accounting frameworks used by the shortlisted cities and their compliance for consumption-based assessment.*

Type of accounting framework	Number of cities	Consumption based compliant
National Carbon Offset Standard	1	No
The Local Government Operations Protocol	1	No
Scope 1	2	No
Scope 1 and 2	3	No
GPC - BASIC	10	Partly
ALas	1	Partly
LEGGI	1	No
Bilan Carbone	1	Yes
LänderArbeitskreis Energiebilanzen methodology	1	Yes

Appendix C: Determining City Intentionality Using Quantitative Models

The cities on the initial shortlist have been selected because they all reported drops in their CO_2 emissions over recent, though variable, time spans. Whereas these cities have also all displayed an explicit intention to reduce their emissions, there is uncertainty surrounding the true causes of the reported declines because each city operates on top of a shifting backdrop of national and regional trends. For example: A city reporting a 20% decline in a region also reporting a 20% overall decline in emissions has different implications when compared to a city reporting a 20% decline in a region with growing per capita emissions. The salient question to ask therefore shifts from whether a city is reporting reductions at all, to whether a city is reducing its emissions relative to what could be expected if it simply followed broader trends in energy efficiency. This provides much needed context for the analysis of policymaking in the shortlisted cites.

Two models were created to answer this question, each providing an estimate of each city's expected reduction in emissions over the same period as the reported emissions reduction. The variables included in each model are listed in Table 4-9, the results are displayed in Figure C-1, and the sources in Table C-1.

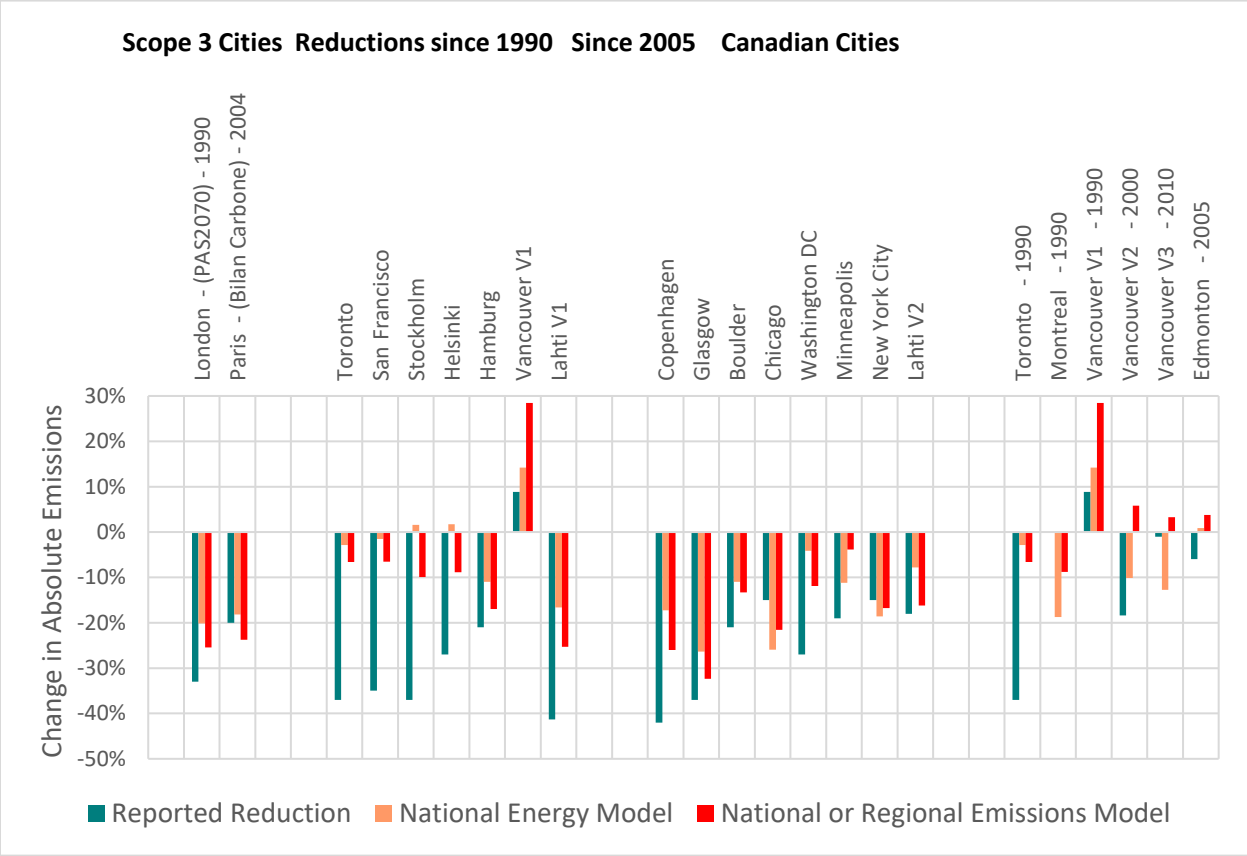

Figure C-1. *Results of the two models.*

Note: All cities except for Paris and London use Scope 2 accounting systems.

Table C-1. *Overview of the sources of data for each model*

Reported Reductions	Emissions Model	Energy Model
• Change in total emissions of an administrative jurisdiction (City, Metro) over a fixed timespan	• Population growth of relevant jurisdiction (various sources) • Changes in emissions per capita at the national level (IEA) • Changes in emissions per capita at the regional level, if relevant (US Energy Information Administration, Canadian National Inventory Report)	• Population growth of relevant jurisdiction (various sources) • Changes in national energy consumption per capita (IEA) • Changes in national CO_2 intensity of power (IEA) • Changes in transport efficiency (IEA) • Distribution of energy consumption by sector: Electricity, Transport, Other (IEA)

Figure C-1 shows that most cities report a greater percentage decline in emissions than would be expected if they followed national or regional trends. Although this constitutes a signal which supports the notion that the cities are primarily responsible for their reductions, there are several additional factors which make it difficult to fully assess the origin of each reported reduction. These include the scope of the emissions accounting process, the time period covered by the reduction and how it overlaps with deindustrialization, and which jurisdiction is reporting the reduction.

1) Scope of Emissions Accounting

Most city results were calculated using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). The GPC provides flexibility about the ultimate scope of the accounting, which can range from BASIC, consisting of Scopes 1 and 2 (territory-based emissions and grid-supplied energy) to BASIC+ which is Scope 3 (all consumption-based emissions) (Wilmsen & Gesing, 2016). However, most cities have opted for GPC BASIC. This means that emissions are territorial in nature and can thus be skewed by trends in economics and urban development which do not respect city boundaries.

Paris and London are the only two shortlisted cities which feature Scope 3 systems of emissions accounting: the Bilan Carbone (Mirabella & Allacker, 2021) and PAS 2070 (The British Standards Institution, 2014) respectively (several other cities, such as Copenhagen, are in the process of expanding the Scope of their own emissions accounting). Both city's reported reductions are significantly closer to the modeled reductions when compared to non-Scope 3 cities, suggesting that much of the difference in results is due to the limited accounting methods currently being used. Comparisons between Paris and London are limited by the fact that Paris's reduction only represents the central City of Paris (which experienced no population growth) and is measured relative to 2004, and London's reduction represents the area Greater London Authority and is measured relative to 1990. Paris's accounting system was also designed to include flights in and out of the city. Nevertheless, the fact that Scope 3 is being employed means that distortions caused by movements of people and industry across the jurisdiction's boundary may be significantly reduced.

The outcomes for Paris and London suggest that Scope 3 accounting is necessary to obtain a clear understanding of emissions trends, and that most other cities would display similar patterns if they changed accounting methods. Finally, it suggests that city intentionality is relatively minimal (London), or even absent (Paris) relative to broader national trends. However, it could be the case that all cities in these

countries are achieving similar reductions through different means, and that therefore city initiative is required to keep pace.

2) Interpreting Scope 2 data: Jurisdictional Boundaries and Time-Periods.

Scope 2 accounting methods are focused on emissions occurring within the territorial boundaries of the city. As such, they are impacted by the long-term displacement of industrial activity across the boundary, which was a widespread occurrence in the 1990s at the tail end of the urban deindustrialization trends experienced by European and North American cities (van Neuss, 2018). Scope 2 data is therefore influenced by both the boundaries of the accounting system and the time-period used:

Jurisdictional Boundaries

The areas represented by the reduction figures range from the region (Hamburg) or metro area (Vancouver), to the core of the metro area (San Francisco, Paris). The cities of San Francisco and Paris only represent 17% and 18% of their metro populations respectively, though this disparity is at its greatest in Australian cities: the City of Adelaide's approximately 25,000 residents represent less than 2% of the metro population. Besides deindustrialization, narrow territorial boundaries may affect the reported emissions in the following two ways: Daytime increases in emissions caused by inbound commuters may inflate per capita figures, and the agglomeration of resources into the central city means that the central city may have a disproportional amount of resources to dedicate towards efficiency initiatives relative to its suburbs (Kübler & Rochat, 2019).

Time periods

City reductions have been reported for a variety of timespans, such as 1990 – 2018 (Toronto) and 2005 – 2019 (New York City). This variability can obscure effective comparisons if a city's emissions profile, representing emissions over time, includes a recent inflection point. This can be the result of broad-based deindustrialization as previously discussed, or the movement of major individual emitters.

The impact of variability due to changes in base-year is best represented by the case of Vancouver, which featured a growth in emissions in the late 1990s caused by an electric power generation plant in the metro area, followed by a steep decline in the early 2000s caused by the plant's diminished operations (Metro Vancouver, 2013). This fluctuation in reported emissions within the boundary of metro Vancouver – which is only relevant because of Vancouver's Scope 2 emissions accounting – means that the selection of different base-years can completely change the reported trajectory of a city: Relative to 2019, Metro Vancouver's emissions have grown by 9% since 1990, reduced by 18% since 2000, and reduced by 1% since 2010. A similar comparison can be made for Lahti (starting in 1990 or 2005). The absence of consistent timespans therefore makes inter-city comparisons less insightful.

Whether the timespan covered includes such an inflection may therefore significantly affect the results, and this pattern can be viewed in Figure C-1: Cities whose reductions are measured relative to 1990 feature substantially larger reductions relative to the models than cities measuring relative to 2005.

A transition to scope 3 accounting should resolve many of the issues identified above. In the interim, the interpretation of results obtained with Scope 2 must be combined with information on the industrial trends present during the reported time-period.

Appendix D: Annotated Bibliography – Theme 1

See separate attachment for the annotated bibliography for:

Theme 1: Measures and Evaluation Frameworks (metrics and frameworks)

Appendix E: Annotated Bibliography – Theme 2

See separate attachment for the annotated bibliography for:

Theme 2: Governance and Capacity Building (governance and policy)