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Beyond domain-led conceptualizations of urban zero-carbon transitions

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Abstract

Rapid, systemic change is needed to achieve zero emissions, but there is uncertainty about how or where to intervene in urban systems. Drawing on the work of Donella Meadows, we apply a Leverage Points Perspective to identify and characterize points of system-level intervention that emerge from a study of climate action in Calgary, Canada, which was unique in applying a mixed set of academic approaches. Reflecting on Meadows' and other frameworks for conceptualizing complex systems change, we discuss the challenge of conceptualizing change, a task of unique urgency in the context of the climate emergency. Too frequently, we argue, approaches focus attention on specific modes or forms of action seen to have the greatest opportunity for affecting change in place of the complex chains of actors, objects, and processes that collectively are the key to a deep and sustaining transition. We conclude by exploring how the insights of the Leverage Points Perspective and other approaches can be brought together to inform practical action, and by examining how related theoretical work on provisioning systems and applied work on urban Climate Commissions may be drawn on to advance understanding of how to deliver urban systems change.

Keywords: *climate action, cities, Leverage Points Perspective, Climate Commissions*

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1. Introduction

Cities' importance to action on climate change is so well established that the case for a focus on cities has become something of a cliché in urban literature. Cities are not only home to a majority of the world's population, income, energy use, and emissions, but also their share is growing [1]. Urban policymakers have been making commitments to climate action that (in some cases) far surpass those made by their regional and national counterparts [2, 3]. And urban areas are a leading source of, and location for, new approaches and experiments in climate action [4].

Whether this importance should be a cause for optimism or pessimism regarding the future of climate action, however, has often depended on the disciplinary lens of the author. Literature from economists and engineers has frequently (but not always) presented a more optimistic perspective through the development of roadmaps, pathways, and scenarios for urban areas that achieve necessary transitions [5–8]. On the other hand, literature from urban theorists, human geographers, and wider authors frequently presents a more cautious or critical perspective.

Developing means for constructive interaction between these literatures is critical both to advancing an overarching "urban theory" or "science of cities" [9–14] and to realizing effective urban action. In response to this challenge, a large number of conceptual frameworks have been developed that feature hierarchies of domains of action in complex systems toward sustainability [15–19].

Among these frameworks, Meadows' Leverage Points Perspective [20] is seen as a foundational approach for understanding intervention in complex systems [15, 21]. Recent work by Abson et al. [15] categorizes Meadows' hierarchy into four domains. The deepest leverage points are categorized within the domain of "mental models" and relate to systems of values and mindsets. A second set of "deep" leverage points include elements of system structure, including rules and regulations established by institutions. Finally, "feedback loops" and "parameters" are two shallow domains of leverage that are proximate to sustainability outcomes and relate to specific technologies and practices that take place in an existing system (**Figure 1**).

In this article, we apply Abson's [15] development of Meadows' Leverage Points Perspective to a study of climate action in Calgary, Canada. We find that a Leverage Points Perspective is effective for identifying and characterizing climate action opportunities in Calgary. Further, we find that Abson's development of Meadows' Leverage Points helps to draw attention to the need for deep system-level interventions for effective climate action.

At the same time, the study offers an opportunity to explore the challenges of frameworks based around hierarchies and domains

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of interventions, such as Meadows' Leverage Points. While authors have suggested that a Leverage Points Approach can enable the understanding of coordination between places of intervention [15, 21, 22], we make the case that the process of categorizing interventions, and the prescribed ranking of those interventions, can make the integration of action more challenging. Indeed, the process of specifying and characterizing domains, we argue, can create silos between disciplinary approaches and focus our attention on the "depth" of domains rather than the unrealized potential of coordinating between them.

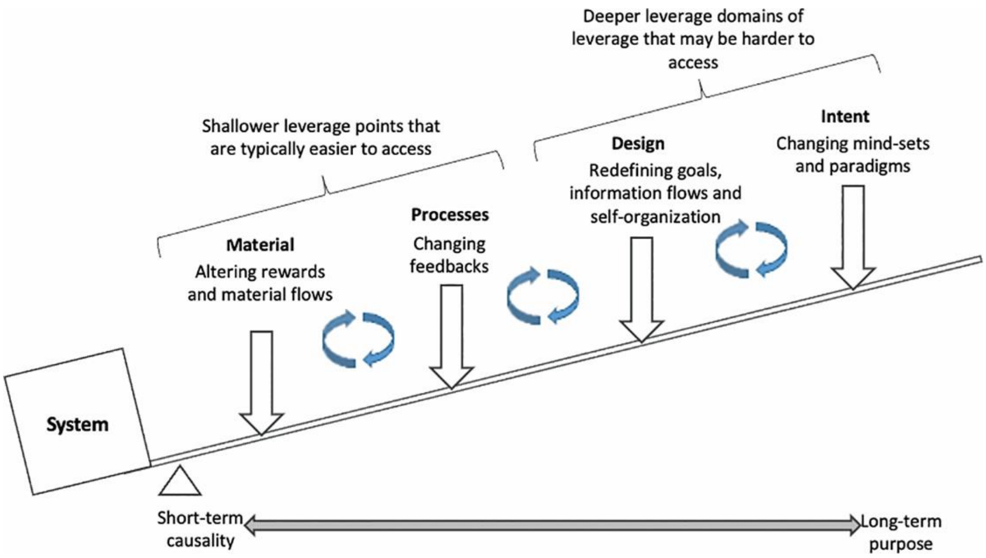

Figure 1 • Domains of leverage in complex systems, adapted from Abson [15] and based on Meadows [20].

Two recent developments are raised that may offer pathways for moving beyond domain-led conceptualizations of systems change. In academia, the emerging concept of provisioning systems offers a conceptual approach that works to understand the chains of practices, policies, behaviors, and mindsets that enable consumption. In the practitioner's sphere, the development of Climate Commissions in a growing number of UK cities provides an institution connected with, but fundamentally independent from government, which can join up latent demand and capacity for action from civil society, the private sector, academia, and wider stakeholders.

2. The case

Home to the headquarters of nearly every oil and gas company in Canada, a sprawling urban footprint, and one of the world's highest levels of per capita GHG emissions [23], Calgary gives the impression of being the quintessential high-carbon North American city. The political and techno-economic context of Calgary, however, is more nuanced than first meets the eye.

Despite the city's dependence on the fossil fuel industry, municipal governments have pursued increasingly ambitious environmental initiatives. From 2004 to 2006, "Imagine Calgary" led to the city's first Sustainability Plan, which included a commitment to reduce the city's environmental footprint below 7.25 hectares per person by 2036. Following this, the city's 2009 Master Development and Transport Plan, unanimously approved by the council, promoted densification and active transport by phasing out subsidies for suburban development, targets for infill development in the city, and investments in public transport [24]. In 2017, Calgary established a climate change program; in 2018, the council unanimously approved a climate action plan that included a target of reducing city-wide emissions 80% by 2050 (from 2005 levels); and in 2023, the city is in the process of finalizing its net-zero-emission 2050 target.

Concurrent to the merging of urban and environmental agendas in the city, however, has been a shift in national politics. While historically political and economic powers were seen to be concentrated along the narrow corridor of the St Lawrence watershed in Eastern Canada, immigration to the West, the development of the oil sector, and trade with China have shifted the axis of Canadian politics. This breakdown of the so-called "Laurentian Consensus" has led to an increasingly contentious divide in Canadian politics between those who view Alberta's oil sector as a critical driver of the national economy and those who are concerned about the growing environmental impact of the sector and the need for economic diversification. Thus, the debate over climate action in Calgary has been conducted in the shadow of a wider national argument.

3. Methods

To support the development of a Climate Action Plan for the City of Calgary, the Economics for Low Carbon Cities Calgary report was produced by a team from the University of Calgary and the University of Leeds in 2018 [25]. The methodology comprised three main elements: a techno-economic analysis to understand the opportunity for specific technologies and measures to achieve GHG emissions reductions, a multi-criteria analysis (MCA) survey designed to capture the opinion of the general public on climate action, and focus groups with members of the city and other key stakeholders to understand the perspectives of urban policymakers on the opportunity and barriers to action in the city. Further information is provided in Supplementary material.

3.1. Techno-economic analysis: climate action in Calgary from the perspective of data science

Options for GHG emissions mitigation were identified using established emissions protocols that consider fuels and electricity consumed in Calgary. The methodology followed for the techno-economic analysis follows that of similar studies established in the literature [26–28]. The work in this section comprised three steps: baseline development, options appraisal, and scenario development.

To establish the baseline, information was collected on a variety of technical and economic variables, including the building stock, registered vehicles, energy prices, population demographics, and land-use plans. Next, low-carbon options were evaluated individually to determine their financial case and "carbon case". "Carbon case" here refers to the ability of measures to remove or avoid creation of GHG emissions compared against the business-as-usual alternative assumed in the baseline. Cost-benefit analysis is employed as it matches the analysis used by the City of Calgary. The analysis included only Scope 1 and 2 emissions, following the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). Although this approach is widely followed, consideration of emissions embedded in supply chains and the production of goods and services outside of the city—Scope 3 emissions—is increasingly seen as an important area for urban areas to direct attention toward [25, 29]. Not including Scope 3 emissions is therefore a limitation of this analysis.

Finally, three scenarios were developed to outline all actions that could be completed across the city under different economic rationale. The cost-effective scenario involved the actions that provided the strongest economic return at 8% discount rate based on consultation with stakeholders. The cost-neutral scenario involves actions that maximize emissions reductions while ensuring that the indicated rate of return across all investments remains greater than zero. The technical potential scenario explores the emissions reduction potential with the maximum investment in measures. In each case, the interactions between measures, including where actions are mutually exclusive, are considered. Further information on the key assumptions and modeling approaches used can be found in the technical appendix.

3.2. Multi-Criteria Analysis (MCA): exploring the political and social acceptability of climate action in Calgary

In order to capture the public's perception of the actions investigated in the techno-economic analysis, an online survey was completed by 262 participants. The survey evaluated the low-carbon actions based on seven criteria:

1. Economic development
2. Environmental co-benefits
3. Accessibility and equity
4. Human health and well-being
5. Capacity for implementation
6. Political acceptability
7. Public acceptability

The City of Calgary distributed the survey to members of public stakeholder groups organized to provide the city with feedback on their climate action program and was also publicized through the city's Twitter account. The participants responded in two steps. First, respondents weighted each criterion based on the relative importance each person determined a criterion merited. Second, respondents scored each of low-carbon actions based on each criterion. The results were then collected with the highest scoring actions being those that scored positive on important criteria, the lowest scoring actions scoring negative on important criteria, and others in between scoring neutral or on less important criteria.

3.3. Focus groups and expert interviews: processes of urban climate action at the City of Calgary

The consultation consisted of ten three-hour workshops, with two workshops focused on each of the domestic, commercial, transport, and waste sectors and two workshops covering all sectors. Workshops were conducted with stakeholders possessing expertise in the sectors being assessed. These experts included building owners and constructors, operations managers, representatives of environmental organizations, city officials, energy providers, and community advocates and members of civil society.

The project group provided the experts with the methodology of the techno-economic analysis, how the actions and scenarios were developed, and the preliminary findings of the report. The experts provided their feedback on the actions and scenarios, as well as the underlying data and assumptions used for the analysis to give a clearer picture of what impacts would look like within the Calgary context. The group sessions allowed for an open discussion on the analysis so far, what adjustments should be made, and where the analysis should go.

Following the group sessions, experts provided individual and more detailed feedback in interviews with members of the project team. The interviews were free-form, allowing the experts to discuss what they felt was most important to their sectors from the perspective of the report, as well as identify issues the report may have overlooked. Results of the focus groups and interviews were coded using the methodology described Burch 29], which organizes barriers into "structural/operational" barriers, "regulatory/legislative" barriers, and "cultural/behavioral" barriers. "Structural and operational barriers" Burch [30] consider the configuration of government and governing processes, and the ways that these can affect prioritization and implementation of actions. "Regulatory barriers" consider the policy tools at the disposal of the local government and the avenues of influence the local government has on other layers of government. Finally, "behavioral barriers" capture leadership capacities and institutional cultures.

4. Results and analysis

4.1. Techno-economic analysis

Figure 2 shows high-level results for each scenario. Focusing on the measures that generate financial returns, the "cost-effective" scenario shows potential emissions reductions of more than 40% through 2050 while generating more than $4 billion in annual savings. The capital investment required for this scenario, however, is substantial at $12.4 billion.

The cost-neutral and technical potential scenarios suggest that achieving higher levels of emissions reductions through further interventions would come at a high cost. Applying addition measures or swapping "shallow" measures for "deeper" measures until the scenario as a whole is close to breaking even (defined here as a net present value of approximately zero at a discount rate of 3%) increases GHG savings to 70% in 2050 but at a cost of more than $100 billion. Key measures from these scenarios are shown in **Table 1** ranked by cost effectiveness.

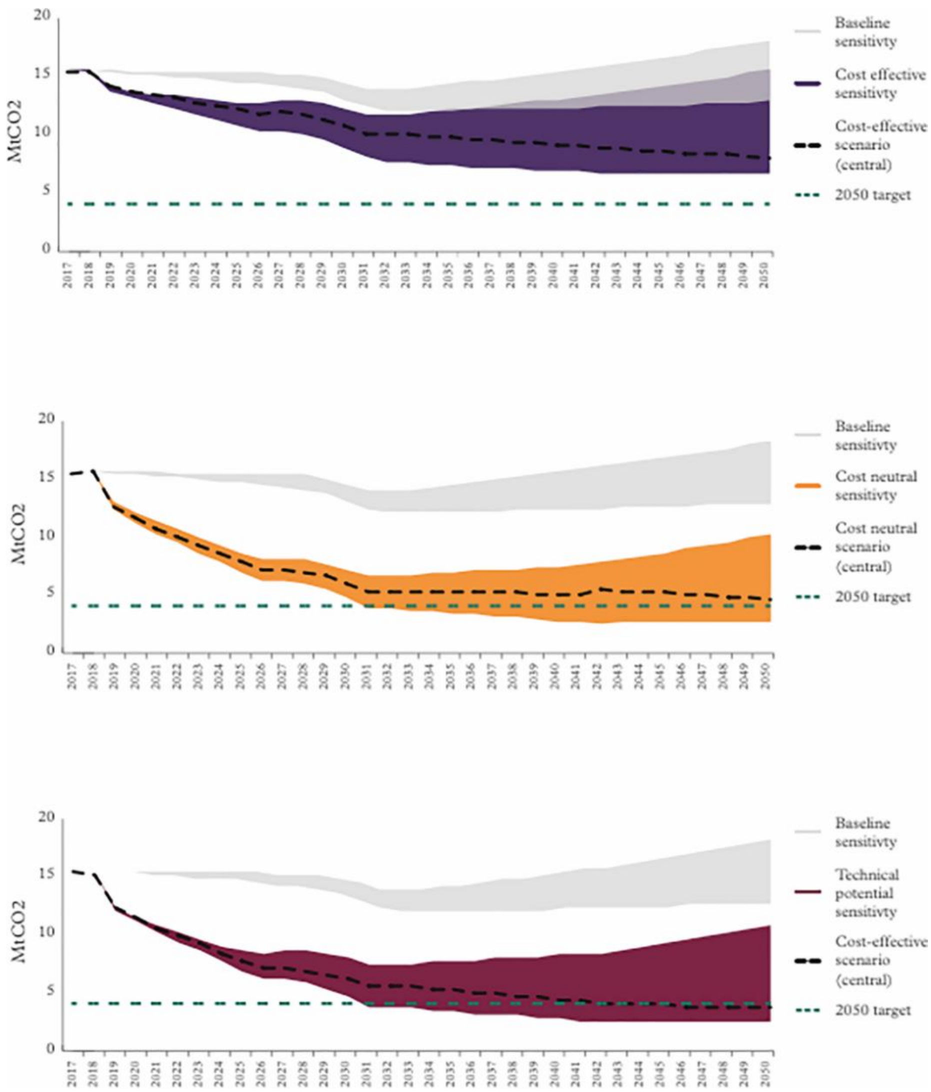

Figure 2• GHG pathways by scenario, adapted from Sudmant et al. [25].

Table 1 • Top ten cost-saving measures per tonne carbon reduced

Sector	Sub-sector	Intervention title	$ saved per tonne of GHG emissions saved
Land Use		Municipal Development Plan (MDP): Land Base Growth Reduced from 45% to 27.6% from 2009 to 2070	$300–$325
Transportation	Private Vehicles	Parking Levies in Municipal Spaces increase by $3–$8/hour, $12–$32/day	$270
Transportation	Goods Transportation	Electric Vehicles (light, medium, and heavy vehicles)	$225–$245
Transportation	Private Vehicles	Hybrid vehicles (50% by 2030)	$70–$140
Transportation	Private Vehicles	Electric vehicles (50% by 2030)	$50–$110
Residential Buildings	Existing Apartments, Townhouses, and Single-family homes	Retrofit 1: Lighting and appliances	$60–$80
Commercial Buildings	Existing Retail, Office, and Warehouse spaces	Retrofit 1: Lighting and appliances	$40–$60
Residential Buildings	New Apartments, Townhouses, and Single-family homes	Current Building code plus upgraded lights and appliances	$30–$40
Commercial Buildings	Existing Retail spaces	“Moderate” to “Deep” Retrofit involving improved insulation, windows, and upgraded appliances	$20
Commercial Buildings	New Office spaces	Measures reducing building energy consumption by 30–50%	$10–$20

Information from the scenarios and individual measures analysis can help to guide long-term planning in the city. For example, existing retail office and warehouses offer a larger opportunity (in emissions savings and economic returns) than homes due to the fact that relatively "deep" retrofit measures achieve financial returns. A shift to electric vehicles is found to support decarbonization, but with emissions savings concentrated toward the end of the decade and dependent on grid decarbonization. New investments in public transport, most significantly the Green Line light rail extension, are found to have limited impacts on emissions relative to their substantial cost unless they are followed by very substantial increases in densification around stations. Perhaps most significantly, a major shift in land-use development in Calgary toward the 2015 millennium development plan is found to have the most significant case in both economic and GHG terms. This is due to the fact that changes to land use could affect emissions from both buildings and transport in synergistic ways, enabling district heat systems and other low-carbon technologies for buildings, but also more public and non-motorized transport.

These findings emphasize the material and economic scale of the challenge facing Calgary. At the same time, results highlight the potential for changes in the material and technical parameters (domains of leverage 1 and 2) of different aspects of Calgary's energy system to affect substantial reductions in GHG emissions.

4.2. Multi-criteria analysis

Table 2 • Measures ranked highest in the MCA survey

Sector	Measure	Score
Waste	Prevention (5–10% target)	24.5
Distributed Energy	Solar PV	17.4
Domestic	New Low—Upgrade lighting and appliances	15.5
Waste	Landfill gas utilization	15.3
Domestic	Retrofit Low—Upgrade to current building code	13.6
Commercial	Retrofit 1—Shallow Retrofit	14.3
Transport	Increased cycling and walking to work	13.0
Domestic	New Medium—Upgrade to mid-optimal insulation	12.3
Commercial	New 1—"Shallow" Standard For Buildings	12.4
Land-Use	Best practices in green field developments	11.0

Results from the MCA (**Tables 2** and **3**) suggest that the actions perceived as less invasive or disruptive and lower cost would receive more support from members of the public than more aggressive interventions. While measures that required individual changes in habits, such as waste prevention and alternative transport, were seen more positively, impacts on individuals' choices and expenditures, such as the adoption of fuel-efficient vehicles and increased parking levies, were seen more negatively. Interestingly, solar PV had one of the highest and lowest overall scores, depending on whether it was presented as an individual action (positively) or within a package of measures (negatively). This suggests that the approach to implementation is important in shaping public perception of different low-carbon options.

Table 3 • Measures ranked lowest in the MCA survey

Sector	Measure	Score
Waste	Incineration	−12.4
Transport	Increasing parking levies	−11.1
Transport	Reduced car ownership (20–40% target)	−8.0
Transport	Biofuel (B20)	−7.1
Waste	Landfill gas flaring	−5.1
Transport	Hybrid vehicles (50% target by 2030)	−1.0
Domestic	Retrofit Very High—Addition of solar PV array	−0.9
Transport	Electric vehicles (50% target by 2030)	−0.9
Distributed Energy	Distributed Wind	0.3
Transport	Compressed natural gas heavy vehicle transport	0.4

There is also evidence of tension around how climate actions are seen to contribute to, or conflict with, the future of the Calgary economy and the city's identity. While more costly or disruptive measures uniformly received lower scores for "public acceptability" and "economic impact" (among other indicators), the lowest scores for these criteria by a significant margin were for actions in the transport sector. Measures such as bike lanes, reduced car ownership, and electric vehicles were all seen as particularly controversial, with comments emphasizing the importance of "home-grown solutions" such as compressed natural gas vehicles and the development of "green gas" for heating. In **Figure 3**, it can be seen that across measures respondents perceived significant potential for human health benefits but a significant challenge around the public and political acceptability of low-carbon measures.

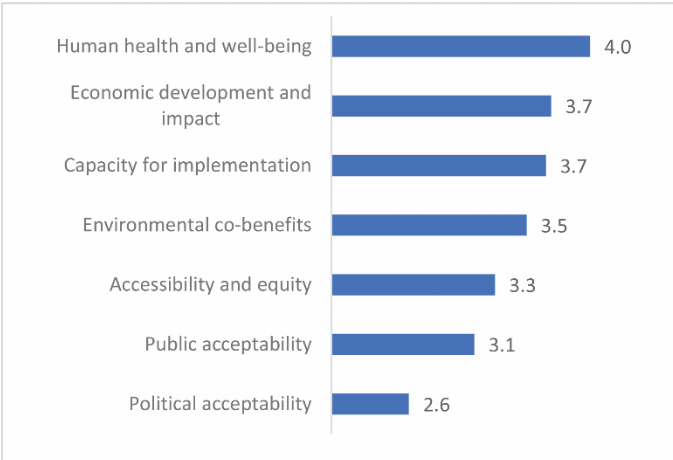

Figure 3 • Average measure scores by multi-criteria component with 5 as the highest score and 1 as the lowest.

More generally, respondents noted that Calgarians were already facing a challenging economy and would respond poorly to measures that came at a significant cost or that were not framed as focusing on jobs and welfare. These results emphasize the role of social and political lock-ins and the ways in which these lock-ins are connected with overarching "mindsets" and systems of belief identified as deep leverage points by Meadows [20].

4.3. Workshops and interviews

"Structural and operational barriers" Burch [30] consider the configuration of government and governing processes, and the ways that these can affect the prioritization and implementation of actions. At the core of these are a set of inter- and intra-organizational challenges.

In workshops and discussions, interviewees raised the challenges of budget cycles, both within the municipality and at the provincial and federal levels, and the ways in which these are a barrier to long-term and politically sensitive projects (such as climate action). Interviewees also discussed the challenge of measures involving the coordination of more than one department or more than one jurisdiction, which make action dependant on the alignment of different actor's interests, timelines, and priorities. In Calgary, this challenge has particular relevance around development planning, with neighboring municipalities competing to provide a lower-cost alternative for residents and businesses.

Regulatory barriers consider the policy tools at the disposal of the local government and the avenues of influence the local government has on other layers of government. Interviewees emphasized the need for the city to learn from other municipalities implementing innovative programs and supporting new technologies, particularly electric cars. Interviewees also discussed the challenge of negotiating for environmental measures as part of the planning process for new developments and the extent to which key regulatory powers are held by the provincial and national governments.

Finally, "behavioral barriers" capture leadership capacities and institutional cultures. Interviewees noted that the municipality primarily sees itself as "enabling action" from businesses and citizens and is loath to be seen as "putting up red tape". To illustrate interviewees described how the city works closely with organizations such as "Economic Development Calgary", a non-governmental body tasked with improving the city's economy. In addition, some view the city as "primarily a service provider". This mentality limits the scope for the city to directly act to address climate change and shifts the city toward more indirect roles. These indirect roles could include convening stakeholders, lobbying other levels of government, partnering with stakeholders, or coordinating the action of other stakeholders.

Interviewees also noted that there can be a lack of "shared goals" between different parts of the municipal government. This may reflect a "structural and operational" barrier emerging from the "siloing" of different responsibilities in local government: different departments focusing narrowly on different sets of goals and as a consequence failing to work together on crosscutting challenges like climate change. This may also reflect conflicting visions between incoming and outgoing (department or city) leadership, or a decentralized organizational culture that allows a great deal of freedom for different departments/units to develop their own goals. In the context of climate change, where coordinated action is essential, this could be a challenge to more ambitious action led by the city.

These connected challenges collectively point to the need for ways to break through "organizational lock-ins": ways that institutional structures in the city inhibit low-carbon action and that are primary confined to Abson's third domain of Meadows' Leverage Points. At the same time, the way different members of city government and leadership view the role of the city in the context of climate change calls attention to Abson's fourth domain referring to systems and beliefs, values and mental models.

5. Discussion

5.1. A Leverage Points Perspective on climate action in Calgary

A critical need for attention to domains of "deep leverage" emerges across the study of climate action in Calgary, in line with a growing literature on place-based sustainability [31, 32].

Although a wide range of actions achieve large emissions reductions at low or no net cost, many of these interventions can be seen to be relatively "shallow" in their effect on the wider system, affecting the "parameters" of the urban system but not its fundamental structure, rules or design. Housing retrofits and commercial building standards, for example, generate meaningful emissions mitigation only in a scenario where substantial investment is made by an investor willing to accept minimal or negative returns. And to the extent that some measures leverage existing capacities and infrastructures, others may inhibit longer-term change and enhance lock-in to existing socio-technical systems. Electric cars, for example, may reduce emissions from transport at the cost of encouraging a continued reliance on private transport, long-distance commuting, and low-density development.

More significantly, the MCA (Section 4.2) and interviews with policymakers (Section 4.3) reveal challenges around the implementation and governance of techno-economic interventions. Measures in homes and offices require the development of financing schemes and regulatory measures from each of municipal and provincial governments; changes in land-use decisions create winners and losers in the property market; and promotion of electric vehicles may raise the ire of those who depend on the oil and gas sector and see the industry as part of the identity of their city. Acting on these measures, in other words, is constrained by features of system structure, mindsets, and systems of belief.

The survey of wider members of the public and interviews with city staff help to characterize these "deeper" leverage points. From the survey of members of the public, a clear challenge—and leverage point—emerges around the degree to which participants see climate action as enhancing or detracting from their well-being. This is seen across participants in the way more ambitious versions of measures of all kinds received lower scores across criteria. It is also seen in the specific feedback provided by respondents, with measures to reduce natural gas use in buildings and to adopt electric vehicles receiving conflicting feedback.

Understanding stakeholder perspectives, acknowledging conflicting sets of values, equipping citizens with a common and coherent science-based narrative, and making citizens co-creators in the development of responses to climate change, is a theme of a growing body of work on citizens assemblies [33], citizen science movements [34], urban labs [35], participatory games [36], climate juries [37], and climate commissions [38, 39]. By supporting deliberation and engagement (at a level far beyond that which was achieved by the survey is this analysis), these processes are finding success in achieving areas of consensus and support for bold action [37], making a case for Calgary to continue its process of engagement with stakeholders around its climate targets.

Interviews with staff at the City of Calgary reveal a deep leverage point around the role of political leadership. Members of the city highlight leadership as a means of establishing priorities and helping to coordinate departmental goals. Beyond their role within the city, charismatic political leaders can also serve as ambassadors, building connections with other urban areas and between the city and international actors, bringing capacity, funding, and knowledge the city would otherwise not have access to [40–42].

Critically, however, the potential of these deeper leverage points is dependent on analysis of the technical and material context. The necessity of action on land use and urban development in Calgary, for example, emerges from an analysis of existing and future travel patterns, low-carbon transport technologies, the electricity grid, and the relative costs of urban expansion versus infill development. A specific need therefore emerges for political leadership to be directed toward fulfilling the goals of the Calgary Millennium Development plan and coordinating transport and development with neighboring municipalities. Similarly, techno-economic analysis characterizes the challenge of shifting Calgary to a low-carbon future in terms of the financial costs, the impacts on employment, and the future of the city's economy, helping policymakers address the concerns and underlying narratives held by those who support and oppose action. These findings mirror work in Istanbul and Shanghai, where the urban renewal and new mobility, respectively, offer unique opportunities for supporting urban sustainability transitions if an enabling environment for these interventions is developed [43].

In this way, the separation between deeper and shallower domains of leverage breaks down as we consider the interdependencies between interventions. In the place of a hierarchy of greater and lesser places for action, "chains of leverage" [15] emerge that are specific to different aspects of the urban system and that will be unique between urban systems. In practical terms, this suggests that approaches to urban action that strive for the greatest breadth—in the number of perspectives considered and the number of stakeholders involved—may be advantageous to approaches that achieve substantial depth but fail to characterize the dependencies and contingencies that leverage points depend on. Moreover, such approaches may fail to capture opportunities for synergies between actions, such as those between mitigation and adaptation interventions in urban areas [44].

While authors have suggested that a Leverage Points Approach enables the understanding of coordination between places of intervention [15, 21], the processes of "categorization"—understanding a domain of intervention in a specific urban system—and "integration"—understanding how domains interact—are not necessarily complementary.

5.2. Beyond causal versus teleological approaches to urban system change

The boundaries between "casual" and "teleological" explanations of systems change (the former focused on the parameters of urban areas and the latter on mental models and institutional structures) [15] and between "city scientists" and those trained to see "contingent meanings and subjectivities" [45] prevent the development of more complete theoretical and applied approaches to urban climate action [15, 46]. While Meadows' Leverage Points Perspective offers one approach to bridging disciplinary perspectives, it exists among a number of conceptual perspectives and frameworks that employ the use of domains to conceptualize places for intervention (e.g. [15–18, 47]).

A limitation across existing domain-led conceptualizations, however, may exist with the balance they achieve between reducing the universe of pathways to systems change and generating a false sense of concreteness about the way those changes take place. Characterized as a teeter-totter [15], gears [16], and concentric circles [47], existing "domain-led" conceptualizations are fundamentally "tree-like" systems with discrete and hierarchical places for intervention.

Despite insisting, and in some cases strongly developing and exploring [16], the inextricability of social and technical systems, domain-led conceptualizations can therein inadvertently reproduce the separation they seek to repair. This can lead to a siloing of disciplinary perspectives and a focus on the "depth" of different realms rather than the latent potential of combinations of objects and processes between them. It can also contribute to the false implication that leverage in a given domain necessarily translates to changes in other domains. In this way, the metaphor of a lever can be mistaken for affecting linear material change rather than being applied to a moving and dynamic world [48].

A characterization of systems change that focuses on "domains" can also be immobile to revision as conditions change and understanding evolves [49]. This is of particular relevance to urban sustainability as the field has grappled with rapid environmental and socio-economic change, and as it has recognized that environmental and biophysical boundaries need to be a part of frameworks, rather than being presented as exogenous sets of targets and constraints leverage points and other frameworks need to act within [50].

Domain-led conceptualizations may also inadvertently obscure the degree to which pathways to rapid systems change depend on factors neither "city scientists" nor those trained to see "contingent meanings and subjectivities" [45] yet well understand. Contradictions, conflicts, and unintended consequences as domains interact seem increasing the rule rather than the exception in well-meaning efforts to meet human and environmental challenges simultaneously [51, 52].

Emphasizing a need for "messiness" or "deeper complexity" gives the impression of placing academic theorizing before practical action. Acknowledging this complexity, however, may be key to advancing real world climate action.

A number of authors are taking approaches to navigate between the complexity/messiness of real-world urban systems and the necessity of conceptual approaches to guide action. Birney [48], for example, points practitioners to the qualities of systems change that collectively can be used to understand system dynamics, and that can be translated into strategy and interventions. This work has particular value for Climate Commissions, enabling institutions for local climate action that have been developed recently in Leeds, Edinburgh, and Belfast. By bringing together private, public, community, and third-sector actors, climate commissions respond to recognition of the need for place-based local-level initiatives [53] and experiments with governance arrangements [54, 55]. In this way, Climate Commissions support urban transitions by tapping into latent demand for action, and unrecognized connections and capacities that exist between diverse sets of local actors.

In the academic sphere, the emerging concept of provisioning systems offers a framework for supporting these lines of inquiry. Similar to “systems of provision”, provisioning systems assess the elements that work together to satisfy human needs. Different from systems of provision, provisioning systems move beyond the unique political economy of specific human needs to the development of a framework across human needs, and in so doing may help to answer a call from Davelaar [56] for the development of more holistic metaphors of nested leverage points.

By starting with biophysical constraints and the complementary concept of social boundaries [50], provisioning systems make system boundaries, thresholds, limits and tipping points, foundations of the framework. By focusing on feedbacks and power relations that connect between physical and social systems, provisioning systems make the interconnection between different actors, agents, and objects the focus [57, 58]. And by exploring how different societies turn resources into the things people need in different ways and with differing degrees of efficiency, provisioning systems offer a framework within which evolving and competing revisions of the nature of systems change can be compared and contrasted [59].

6. Conclusion

Drawing on Meadows’ Leverage Points Perspective, we characterize the challenges and opportunities facing Calgary, Canada, as it shifts to a zero-carbon future. Reflecting on these challenges, the value of a Leverage Points Perspective specifically, and of wider domain-led conceptualizations of complex systems change, is made clear. These approaches provide a means of bringing together different sources and types of knowledge, and do so in a way that helps to characterize opportunities for deep leverage. At the same time, as we explore the connections between domains of leverage that emerge from the study of Calgary, a clear limitation of domain-led approaches becomes apparent. By prescribing the domains that different sources of knowledge apply to, and the depth of different domains without reference to the case in question, domain-led approaches can silo disciplinary perspectives and obscure the need for integrated interventions.

Addressing these limitations may be aided by emerging theoretical work on provisioning systems, and applied work being developed by Climate Commissions. In each case, a core aspect of the conceptual approach lies in identifying chains of actors, objects, and processes, therefore moving away from a focus on specific actions or modes of action and toward the systems actors, objects, and processes that can achieve systems change. For practitioners, awareness of the limitations of domain-led characterization of the zero-carbon challenge can help to shift attention to linkages between objects and processes that are key to realizing change. This can include working with stakeholders to map capacities, track progress on action, and co-produce pathways to net-zero. For the academic community, analysis focusing on the chains of actors, objects, and processes may be particularly valuable where it is applied to Scope 3 emissions, an area of emerging focus.

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Conflict of interest

The authors declare no competing interests.

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