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Trading off sustainable development in Canadian cities: theoretical implications of SDG 11 indicator aggregation approaches

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Sustainable Urban Development requires an optimization of multi-dimensional targets across social, economic, and environmental pillars of development. These multi-dimensional targets are largely captured by the United Nations Sustainable Development Goals, which comprise 17 goals spread across pillars of sustainable development. The pursuit of these targets, however, often exposes synergies and trade-offs between the goals. Broader discussions of trade-offs between human and natural capital have been conceptualized along the contours of weak versus strong conceptualizations of sustainable development. This challenge is exposed not only in strategizing sustainable urban development but also in measuring progress toward that aim. With this background in mind, there is limited research to indicate how Canadian cities are progressing toward the achievement of the Sustainable Development Goals and the extent to which trade-offs in SDG performance should be treated. This investigation collected indicators for SDG 11, Sustainable Cities and Communities, on 18 Census Metropolitan Areas in Canada for the purpose of designing an index of SDG achievement. The resulting index aggregation measures compared performance depending on whether the CMAs were allowed to trade-off performance across the SDG 11 indicators. The results expose the significant role of non-compensatory aggregation methods (which do not allow the trade-off of performance) when measuring sustainable development. The implications of these findings demonstrate the need to consider policy pathways that address these trade-offs and consider how that progress is measured.

KEYWORDS
sustainability, Sustainable Development Goals, SDG index, normalization, aggregation

1. Introduction

Sustainable development has shifted to a governance approach that frames cities as a catalyst for sustainable development rather than as a cause of sustainability challenges (Parnell, 2016; Zinkernagel et al., 2018). The importance of the SDGs in the accomplishment of sustainable development is well-recognized. However, the adoption of the SDGs and their indicators are facing challenges of common interests, standardized methodology, availability of reliable data, performance benchmarking, consistent reporting, and lack of institutional capacity to operationalize indicators (Simon et al., 2015; Klopp and Petretta, 2017).

The SDGs provide a comprehensive guide to policy development and governance to achieve sustainable development. It provides a framework of 17 goals with over 230 indicators to operationalize actions and monitor progress toward greater sustainability (UN, 2015). However, contextual challenges, local objectives, and lack of understanding led to misunderstandings, inconsistent measurement, and largely unevaluated outcomes. Since the adoption of SDGs in 2015, disagreements and discrepancies have emerged between national and sub-national levels in setting priorities, measurement of outcomes, aggregation of indicators, and comparison of performance.

Different perspectives and objectives led to diverse paths for achieving sustainability. The sustainability concept may have inherited an operational fuzziness due to the relational complexity of its components, determination of facts, assertion of values, and operational constraints (Gladwin et al., 1995; Gibson et al., 2013). It will require a comprehensive set of core values based on theoretical knowledge and practical implications to guide perspective, problem identification, value judgment, setting priorities, and devising appropriate methodologies to guide the evaluation and decision-making process (Gibson et al., 2013).

The SDGs are set to achieve inclusive and sustainable development, but inconsistencies still exist in setting common objectives, selecting appropriate data, and adopting standardized measurement methodologies (Ruan and Yan, 2022). Despite growing academic literature on SDGs implementation in cities (Graute, 2016; Bibri and Krogstie, 2017), gaps persist in finding a commonly accepted method of implementing and monitoring SDGs (Fenton and Gustafsson, 2017; Allen et al., 2019, 2020; Krellenberg et al., 2019). Given this context, the present investigation has its pros and cons due to differences in methodologies available to measure and compare SDG indicators for Canadian municipalities.

Given the limited research available on SDG achievement within cities, this investigation provides insight into the relative achievement of SDG 11 (focused on sustainable cities and communities) among Canadian cities). In order to do so, this investigation constructs an index of SDG 11 achievement by setting targets for SDG 11 indicators and exploring the theoretical ramifications of aggregation approaches. The implications of these aggregation approaches are explored via a discussion of their link to synergies and trade-offs in sustainable urban development.

2. Literature review

Technological advancements and rapid economic growth in the past century have impacted on socioeconomic outcomes and the natural environment. Alongside improved social outcomes and rising incomes, we have seen the catastrophic impacts of global warming, degradation of natural ecosystems, depleting resources, and high risk of pandemic due to rapid urbanization and unsustainable consumption (Pörtner et al., 2022). Population growth, urbanization, and migration have raised concerns about human well-being due to diminishing natural resources, unequal distribution of wealth, lack of access to health and education, and growing food insecurity (Brundtland, 1987; Sachs, 2012; Pörtner et al., 2022). The scale of human activities has pushed the social and natural ecosystem to a dangerous threshold questioning the sustainability of the prevailing economic system. The gravity of challenges has led to the conceptual emergence of sustainable development that can ensure human survival today and tomorrow (Kumi et al., 2014; Fanning and Hickel, 2023; Rockström et al., 2023).

Concerns that have been previously introduced include the issue of the sustainable yield of natural resources (Smil, 2000). Nineteenth-century industrialization increased the demand for natural resources, completely changing socioeconomic and socio-ecological relationships (Devezas et al., 2008). It raised concerns about protecting the natural environment, the stability of the economic system, and human well-being. In the early twentieth century and following the great depression, the concept of sustainability adopted two approaches: the sustainability of natural resources within ecological limits and corporate social responsibility (Bansal and Song, 2017). However, separating the economy from the environment wasn't an appropriate path. It requires an integrated approach encompassing the broader system in which nature, society, and the market interact (Gladwin et al., 1995; Bansal and Song, 2017; Rockström et al., 2023).

Sustainability is about acknowledging ecological limits, fair distribution of resources, and social justice within and between generations (Rauf and Weber, 2021). It is about restricting human activities within the limits of the carrying capacity of the natural system (Odum et al., 1971; Costanza, 1989; Norde, 1997). The Brundtland Commission report "Our Common Future" consolidated the conceptual description of sustainable development by defining it as the development that meets the need of the present generation without compromising the future generation's ability to meet their needs (WCED, 1987). The world recognized the need and set a common agenda by creating the Millennium Development Goals (MDGs) in 2000. The lessons learned from the MDGs stressed human-centered development and environmental protection as a universal normative base (Arico, 2014; Jayasooria, 2016; Parnell, 2016). However, it was recognized to expand the focus on operational mechanisms and inclusion of all stakeholders for horizontal and vertical integration (Gellers, 2016). Sustainable Development Goals (SDGs) were introduced in 2015 to redefine priorities, define a monitoring framework, foster greater participation, and adopt an integrated approach to sustainable development (Sachs, 2012; Martinez and Mueller, 2015; Jayasooria, 2016). The SDGs emphasize the integration of environmental objectives into socioeconomic planning and development processes at local, national, and international levels (Martinez and Mueller, 2015). It provides a comprehensive framework for monitoring global targets (Ruhil, 2017). The SDGs incorporated a wide range of targets set to achieve human well-being while maintaining economic growth within the limits of planetary boundaries (Kates et al., 2005). Environmental resilience and socioeconomic well-being are inseparable (Rockström et al., 2023). For instance, it is well-recognized that an integrated approach to sustainable development is crucial to combat the climate change impacts (Pörtner et al., 2022). However, contextual challenges due to differences in socioeconomic conditions and access to natural resources make it difficult to achieve a global consensus of setting shared objectives and goals (Griggs et al., 2013). The differences in economic and ecological perspectives make it difficult to agree on setting priorities and trade-offs between economic, environmental, and social objectives resulting in slower progress in achieving SDGs (Ayres and Gowdy, 2001; Sachs, 2012).

Growing material demand due to increasing population influences the ecosystem and changes the relationship between the natural subsystems (Odum et al., 1971). Exponentially growing demand, depleting natural resources, and unequal distribution of resources demand a careful consideration of economic practices and growth models (Costanza, 1989; Jackson, 2017). To meet such challenges, it is necessary to reconsider production and consumption patterns, conserve natural capital, and enhance capacity to meet the growing population's needs (Costanza, 1989; Daly, 1990). The sustainability of the earth's natural system and human well-being are inseparable and require an integrated approach to ensure a safe and just future (Rockström et al., 2023).

Opinion on how to best address sustainability challenges is divided based on social and scientific perceptions, economic objectives, and environmental constraints. For instance, sociology, economics, and ecology take a different approach toward sustainability (Ayres and Gowdy, 2001). Economics approaches sustainable development through income equality between generations, considering income as a notion of human well-being (Dietz and Neumayer, 2007). The ecological approach emphasizes the preservation of the natural ecosystem as a pre-condition for human prosperity and intergenerational equity (Griggs et al., 2013; Rockström et al., 2023). Sociology focuses on preserving norms and values that define inter- and intra-generational relationships (Ayres and Gowdy, 2001). Human well-being and the resilience of the earth's ecosystem are inseparable and require an integrated approach (Rockström et al., 2023). Furthermore, interdisciplinary and geographical constraints add to the complexity of sustainable development (Rauf and Weber, 2021). In addition to interdisciplinary variations, there are differences in approaches due to operational priorities and circumstantial constraints. Hammer and Pivo (2017) summarized operational approaches into three categories: modes and means of economic growth, prosperity as a direct outcome, and preservation of natural capital as the basis of economic planning. Differences in conceptual and operational attitudes led to weak and strong sustainability.

The discussion of weak and strong sustainability concerns the stock of natural capital, its reproduction capacity, and its relationship to human well-being (Dietz and Neumayer, 2007; Rockström et al., 2023). A weak approach to sustainability weighs natural and manufactured capital equally in meeting intergenerational needs and technological advancement can provide a substitute for the depleting natural resources (Hartwick, 1977; Dietz and Neumayer, 2007). This approach to sustainability can only be valid if natural resources are available in abundance, producible, or substitutable (Costanza, 1989; Daly, 1990; Dietz and Neumayer, 2007). The irreversibility of natural resources and qualitative differences between natural and manufactured capital oppose substitution (Costanza, 1989; Ekins et al., 2003). Additionally, natural systems are not only for the supply of raw materials, but they also provide other critical environmental/ecological systems services such as waste absorption, and provision of amenity services necessary for human and natural life support functions (Barbier et al., 1994; Harte, 1995). At the same time, the life support function is the direct determinant of human well-being giving primary value to natural systems that embrace humans and the natural environment intact (Turner and Pearce, 1994; Harte, 1995; Dietz and Neumayer, 2007). These views provide the fundamental argument for strong sustainability to keep environmental protection at the center of development trajectories.

The debate between weak and strong sustainability viewpoints extends to setting priorities to trade-offs between socioeconomic and environmental objectives and inter- and intra-generational equity. According to Bromley (1998), adopting sustainable practices that can preserve natural resource capacity to flourish is better than the quantitative valuation of unknown future needs. Similarly, Ayres and Gowdy (2001) added that acknowledging the equitable rights of future generations on resources and subsequent opportunities can provide a development roadmap that may not require an emphasis on substitution and marginal trade-offs. However, this does not mean the present generation can dismiss the relevance of good practice and behavior (Rauf and Weber, 2021).

Development trajectories are subject to multiple factors, including perceptions, objectives, priorities, and capacity. Sustainable development is achievable subject to balancing political objectives and a complex trade-off between socioeconomic and environmental outcomes (Burch, 2010). Geographical and circumstantial changes set a unique context that influences perception about things, value judgment, and determination of needs. For instance, an operational capacity difference due to the quality of education, infrastructure, and financial capital leads to a significant policy variation between developed and underdeveloped nations (Nagendra et al., 2018; Swain and Yang-Wallentin, 2020). Furthermore, functional efficiency for sustainable development requires financial resources, basic infrastructure, education, health, national and regional connectivity, and strong governance. Therefore, contextual circumstances are vital to developing context-specific policies for relevant groups of sustainable development components to facilitate convergence across sustainability indicators (Ulucak et al., 2020; Wang, 2021; Fanning and Hickel, 2023).

Therefore, contextual policy trade-offs are inevitable to develop purposive strategies to address development challenges (Ulucak et al., 2020). However, socioeconomic demands are not the only objective of sustainability. It requires an integrated approach to governance and stability of urban and economic functions (While et al., 2004; Krueger and Gibbs, 2008). Interdisciplinary multi-level inclusive decision-making structure will ensure a sustainable trajectory rather than a narrow-focused unitary approach such as climate-specific policy development. Ayres and Gowdy (2001) highlighted the importance of recognizing the limitation of market solutions in developing context-specific policy development. Sustainable governance would require a cumulative approach for sustainable trade-offs and synergies between operations and governance. Furthermore, a well-defined operational structure will be required to identify context-specific challenges and priorities, set manageable targets, and deploy various tools to achieve the sustainable development goals (Burch et al., 2014).

Urban sustainable development is a broad and heterogeneous subject. It requires an integrated approach across urban functions and efficient governance to achieve context-specific managed growth (While et al., 2004; Krueger and Gibbs, 2008). A global development agenda evolved through Habitat I, II, and MDGs with an implicit focus on addressing global policies for complex urban functions. SDGs Agenda 2030, followed by the New Urban Agenda (Habitat III), clearly viewed the necessity of a broad and shared understanding of urban policy challenges (Parnell, 2016).

SDG 11 (sustainable cities and communities) is targeting to make cities inclusive, safe, resilient, and sustainable providing a comprehensive policy dimension for managing urban systems (Parnell, 2016; UN, 2017). It promotes equality and equity within cities by realizing everyone's right to adequate and affordable housing, transportation, and a safe and resilient environment. SDG 11 also pledges to reduce the environmental impact of cities, emphasizing strong and inclusive regional and national planning for efficient policy development and governance (Parnell, 2016). Urban challenges are sensitive to the city's local circumstances, including geographic location, natural environment, socioeconomic conditions, and governance structure. The respective factors require local knowledge and stakeholders to take the initiative to develop relevant policies (UCLG, 2018; Bates, 2022). For instance, housing and transportation affordability is a relative term varying geographically which may need to be adequately addressed with a universal definition of affordability (Noring et al., 2022). In contrast, urban policies treat subjects like housing and affordability with a single lens ignoring the rationality of varying socioeconomic structures. Addressing housing and transportation affordability requires the devolution of authority and initiatives at a local scale to adopt a holistic approach to policy development and implement accountability to achieve targets (Wakely, 2022).

Society, environment, and economy are hierarchically nested functions that can not be treated independently (Mori and Christodoulou, 2012; Rockström et al., 2023). The SDGs and their indicators are contextual that require synergies and trade-offs to balance circumstantial constraints and temporal requirements. The trade-offs may diverge or converge between goals, disciplines, or even geographically. The outcome of such negotiations is highly dependent on governance structure, path trajectories, and accumulation of policies. For instance, social policies may not favor equitable environmental outcomes. Similarly, financial capital leverage one group over the others in pursuing green agenda (Pradhan et al., 2017). Targets, indicators, and measuring outcomes rely on differing visions of sustainability, which can then define the inter-relationships among sustainability indicators (Károly, 2011; Meinherz et al., 2020).

Pradhan et al. (2017) conducted an indicators analysis for 227 countries and found a consequential relationship between 169 SDG targets. Despite synergies between the SDGs experienced in many countries, most deal with 40-50 percent of their targets, which can require trade-offs (Pradhan et al., 2017). An interdependence between targets and their conflicting outcomes (such as green energy vs. cost of production) is restricting progress in their goals (Pradhan et al., 2017). Nilsson et al. (2018) proposed a seven-point scale framework by characterizing a possible interaction between SDG indicators regarding complementing, ineffectual, and counteracting behaviors. ICSU (2017) adopted the framework proposed by Nilsson et al. (2016) to test the causal relationship between goals and targets. It is evident that trade-offs are not just limited to input values but equally reliant on the process followed and the valuation of corresponding outcomes.

Generally, local governments are more comfortable with the indicators and targets that emerged from local process groups [as exemplified by City of Surrey (2016) and OECD (2016)]. However, most local data and targets are imperative to local objectives, circumstantial challenges, and capacity that may differ from other communities. Furthermore, a local approach to setting targets and assigning data is generally vague due to defragmented approaches and a lack of measurability (Valencia et al., 2019). The complexity of the urban ecosystem increases uncertainty by considering a single indicator or adopting a composite index ignoring circumstantial variations (Allen et al., 2021). Similarly, SDG targets rely on cross-functional and geographic integration. It poses a further challenge to the management of cross-functional and inter-jurisdictional targets (GTF UN-Habitat, 2016; Ho and Runnalls, 2018; Edquist and Espey, 2019). A systematic and standardized methodology of measurement and reporting across communities will improve measurability, comparability, and alignment of local and national objectives (Weitz et al., 2018; Tremblay et al., 2020; Gustafsson and Krantz, 2021). Local governments, however, would require SDG-aligned complementary metrics that incorporate local objectives and circumstantial constraints (Valencia et al., 2019).

Various approaches and methodologies have been developed and adopted to measure SDG progress locally, nationally, and globally. Some of the methodologies include SDG indices and dashboards that serve as a facilitation tool to monitor performance at all tiers of governance (UNDP et al., 2015). The United Nations is leading by providing a quantitative assessment of SDGs and encouraging voluntary local reviews (Allen et al., 2017; UN, 2021). Similarly, a comparative assessment of institutional performance through various SDG indexes has also emerged recently (Schmidt-Traub et al., 2017; Lafortune et al., 2021; Sachs et al., 2021). Local efforts have been made to perform national and local volunteer reviews on SDGs' performance and to compare cities and provinces as well (McArthur and Rasmussen, 2017; Lynch et al., 2019).

City authorities possess local knowledge of circumstantial challenges and opportunities (Graute, 2016; Klopp and Petretta, 2017), but capitalization of the knowledge depends on their capacity to function (Tremblay et al., 2021). Furthermore, the complexity of urban functions and contextual diversity makes it harder for municipalities to set sustainability targets, choose appropriate indicators, and measure and monitor outcomes. SDGs provide a comprehensive framework to set development trajectories (Parnell, 2016; Kanuri et al., 2019). However, the measurement of SDG targets is methodologically complex due to their multiscale and multi-dimensional scope (Allen et al., 2021). It requires a vertical and horizontal integration of governing policies (Parnell, 2016; Kanuri et al., 2019). Policy integration, operational capacity, and responsiveness will impact progress toward achieving sustainability targets in a rapidly changing urban

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environment. At the same time, it would be hard to measure and monitor without efficient data collection, analysis, and reporting mechanisms. Despite having interests in pursuing sustainability agenda, local governments need help with the operational capacity to identify appropriate targets and their relevant indicators, a standardized methodology for data collection and analysis, and creating stakeholder interest (Klopp and Petretta, 2017). A research gap persists in determining the most acceptable methodology for adopting SDGs locally (Fox and Macleod, 2021; Leavesley et al., 2022).

3. Theoretical implications and research gap

It is difficult for a single organization to impact all SDGs. A further challenge is to aggregate socioeconomic and environmental outcomes. The complexity and lack of consensus on a unified approach to indicators and methods make monitoring progress difficult (Mook, 2019). The available tools lack a systems approach integrating interdisciplinary actions and outcomes (Joss et al., 2015). A sustainability framework defines strategic objectives, engages stakeholders at all levels, facilitates adoption in policy development, and provides tools to gauge progress (Roseland, 2012). SDGs are believed to provide a goalpost for national and local policy development (Mesa et al., 2019). However, it would require a specific framework to translate contextual objectives and constraints into indicators aligning with SDGs (Mesa et al., 2019; Spiliotopoulou and Roseland, 2021).

With the help of several federal departments, Statistics Canada developed the Canadian Indicator Framework (CIF) to measure and report SDG's national progress (Government of Canada, 2023b). For adaptability at a local or institutional level, SDGs measurement and monitoring would require consultation with other bodies such as Sustainability Accounting Standards Board (SASB) and the Global Reporting Initiative (GRI) (Mook, 2019). Canadian municipalities are facing difficulties in aligning master plans with SDGs. It is also because several documents in use, such as business plans, official community plans, sectoral plans, climate action plans, etc., are making it difficult to align with SDGs and maintain consistency (Ross, 2018). Some local frameworks, such as Sustainable Community Plan (SCP) and Community Capital Tool (CCT), are considered helpful in identifying indicators to measure local targets and alignment with SDGs (Spiliotopoulou and Roseland, 2021; Zhou et al., 2022). Although SCPs are widely developed across Canadian municipalities, a gap exists in planning and implementation due to methodological complexity and resource constraints (Zhou et al., 2022).

The literature on SDGs localization has grown since its emergence in 2015 (Weitz et al., 2018; Guha and Chakrabarti, 2019; Fox and Macleod, 2021; Taajamaa et al., 2022). Despite willingness, Canadian municipalities need help transforming locally developed Key Performance Indicators to goal level. The knowledge gap persists in finding a comprehensive approach to localizing SDGs in Canadian municipalities. Canadian municipalities face challenges in identifying measurable indicators to align local targets with SDGs (Ross, 2018; Zhou et al., 2022). Furthermore, targets set at local levels need priority criteria to trade off targets suitable to their context. The complexity of the urban system and the limited knowledge of evaluation techniques make it hard for municipalities to follow a defined approach. It causes operational challenges such as data collection, aggregation, and analysis of the outcomes. Therefore, most Canadian cities rely on relative evaluation rather than absolute numbers due to the lack of data and the measurability of indicators (Tremblay et al., 2021).

The Canadian Indicator Framework initiated the Canadian ambitions to Agenda 2030, setting several targets and indicators to measure progress toward development goals. However, over half of the indicators have no specific target assigned. Canada has defined eleven indicators for SDG 11 covering housing, air pollution, public transport, waste disposal, and a sense of belonging for local communities. Most of them are either without a target or missing data to report up-to-date progress (Government of Canada, 2023b). Without clear benchmarking and no concrete measurement and reporting framework, CIF is not helping to demonstrate a decisive move toward the progress necessary to realize the 2030 Agenda for sustainable development (Smith-Carrier, 2023). Therefore, developing a methodology capable of incorporating multidisciplinary and multicriteria aggregation and flexibility to accommodate contextual variations is crucial. Metrics and indicators based on reliable data streams should demonstrate initiatives and measure progress toward the goal (Mesa et al., 2019).

A further measurement challenge centers on the design of a theoretically appropriate index of sustainable development in cities. In order to effectively aggregate measures of sustainable development, each measure needs to be brought onto the same scale via a process known as normalization (Nardo et al., 2005). Normalization may be carried out by standardizing the scores according to their own relative distribution (measured in standard deviations from each score's mean), measuring the distance of each recorded score from a target value, or setting the upper and lower bounds for a score through min-max normalization (where the upper bound can represent a pre-defined target). If the normalization process includes a set of pre-defined targets, the scales for some scores may need to be reversed (e.g. where lower scores are actually closer to a target) in order to avoid introducing errors in the aggregation of the scores.

Beyond the normalization of scores, the method of aggregation has further theoretical implications for measuring sustainable development. These discussions primarily revolve around the concept of compensability (Munda and Nardo, 2009). Compensability refers to the extent to which scores in a given index can be traded off. As an example, arithmetic means allow for perfect compensability (a city with a poor score can compensate for this poor score with improved performance on another score), while certain ranking procedures, like Condorcet ranking, do not allow for compensability (when cities are compared against one another, a city must perform better on each score across these comparisons). Given that sustainable development conceptualizes the optimization of multidimensional goals, the extent to which those goals can be traded off can have significant theoretical implications for the measurement of sustainable development.

Given the limited research available on SDG achievement within Canadian cities, this investigation provides insight into

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the relative achievement of SDG 11 (focused on sustainable cities and communities) among Canadian cities. In order to do so, this investigation constructs an index of SDG 11 achievement by setting targets for SDG 11 indicators and exploring the theoretical ramifications of aggregation approaches. The implications of these aggregation approaches are explored via a discussion of their link to synergies and trade-offs in sustainable urban development.

4. Methods

4.1. Research objectives

- Create an index of SDG 11 achievements among Canadian urban areas
- Identify trade-offs in sustainable development via a comparison of aggregation methods for the collected SDG 11 indicators.

4.2. Indicators and data sources

In order to set a standard urban area for the comparison of SDG 11 indicators, this investigation used Census Metropolitan Areas (CMAs), as defined by Statistics Canada. Statistics Canada defines Census Metropolitan Areas as:

"an area formed by one or more adjacent municipalities that have a high degree of social and economic integration and that are situated around a core population center. A CMA must have at least 100,000 inhabitants, of which 50,000 or more must live in the core. Once an area becomes a CMA, it is retained as a CMA even if its population declines below 100,000 or the population of its core falls below 50,000. Integration with the core is measured by commuting flows from place of work data from the previous censuses or National Household Survey." (Statistics Canada, 2016).

Using this common spatial definition for the urban boundaries of cities within Canada, the following 18 Census Metropolitan Areas were selected for inclusion in this investigation on the basis of the recency and completeness of the SDG 11 data available for each CMA:

- Calgary
- Edmonton
- Halifax
- Hamilton
- Kitchener–Cambridge–Waterloo
- London
- Montréal
- Quebec City
- Regina
- Saskatoon
- Sherbrooke
- St. Catharines–Niagara
- St. John's
- Toronto
- Vancouver
- Victoria
- Windsor

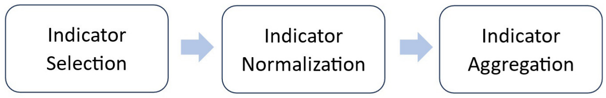

FIGURE 1
Sequence of indices development.

- Winnipeg

For each CMA identified, the investigation followed the following steps in the design of indices to measure SDG 11 performance (see Figure 1).

4.3. Indicator Selection

The first SDG 11 indicator collected for the index in this investigation is SDG Target: "11.1 by 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums." This target is measured via SDG Indicator 11.1.1: "Proportion of urban population living in slums, informal settlements or inadequate housing." In order to localize this indicator within a Canadian context, the indicator is measured using the aligned concept of core housing need. Statistics Canada provides the following definition for core housing need:

"Core housing need refers to whether a private household's housing falls below at least one of the indicator thresholds for housing adequacy, affordability or suitability, and would have to spend 30% or more of its total before-tax income to pay the median rent of alternative local housing that is acceptable (attains all three housing indicator thresholds)" (Statistics Canada, 2021).

The data collected for this indicator were collected in 2016 by Statistics Canada using the 2016 census (Statistics Canada, 2017). Relying on the SDG principle "no-one left behind," the target for this variable is 0% of the population.

The second SDG 11 indicator collected for this index is SDG Target: "11.2 by 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons." This SDG target is measured via the SDG Indicator 11.2.1: "Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities." This indicator has been localized using an existing Statistics Canada indicator, "Percentage of population <500 meters from public transit access point," which was collected in 2020 (Statistics Canada, 2020).

Steg and Gifford (2005) note that sustainable transportation should be conceptualized across a host of multidimensional indicators to mirror to the social, economic, and ecological concerns of sustainable development, including concerns around the distribution of opportunities as conceptualized by social justice. More recently, in a review of sustainable transportation literature from 2000 to 2019, Zhao et al. (2020) noted the emerging importance of evaluating social sustainability issues, including accessibility, when determining the sustainability of transportation systems. Relying on the SDG principle "no-one left behind," the target is 100% coverage of the population.

The third SDG 11 indicator collected for this index is Target: "11.3 by 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries." This SDG target is measured by SDG Indicator 11.3.1: "Ratio of land consumption rate to population growth rate." In localizing this SDG target and indicator, the ratio of land consumption rate to population growth rate was calculated from 1971 to 2011 by Statistics Canada upon request by the investigators (Statistics Canada, 2016).

The intensification of urban growth underpins Land Use Efficiency (LUW) describing the ratio of output to units of land within a given boundary (Cai et al., 2020). While the implementation of intensification has been associated with challenges and requires accessible transportation systems (Searle and Filion, 2011), the potential benefits of the compact city form for productivity, innovation and well-being should not be overlooked (Ahfeldt and Pietrostefani, 2017). That said, based on the literature review by Ahfeldt and Pietrostefani (2017), the potential negative outcomes also cannot be ignored (often occurring when intensification is not integrated within a wholistic urban strategy for transportation, service access, and the conservation of public spaces). In sum, this target is a significant component of sustainable urban development, but its positive outcomes can only be realized when implemented synergistically with other sustainability targets. Given this background, this investigation set the target for this indicator at 1, indicating that the land consumption rate is less than the population growth rate (indicating greater efficiency in land use).

Given a lack of complete, comparable, and accurate data, SDG 11.4 and 11.5 were not included in this index. Instead, the fourth SDG 11 indicator collected for this index is Target: "11.6 by 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management." This target is measured by the SDG Indicator "11.6.2 Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population weighted)." The Government of Canada collects data on the average annual fine particulate matter concentrations (PM 2.5) in CMAs across the country (Government of Canada, 2023a). The data integrated into this index was collected in the year 2016.

Air pollution in cities can be driven by challenges associated with rising emissions stemming from transportation, among other sources, and can have a profound long-term implications for human health and wellbeing (Zhang et al., 2022). That said, the management of urban air quality is a function of the management of urban development. As a result, as with other indicators, urban air quality is a necessary sustainable urban development target but is also dependent upon progress in other sectors of urban development. According to recommendations from the World Health Organization (World Health Organization, 2021), the target set for this indicator is 5 ug/m3.

The final SDG 11 indicator collected for this index is SDG Target: "11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities." This SDG target is measured by the SDG Indicator "11.7.2 Proportion of persons victim of physical or sexual harassment, by sex, age, disability status, and place of occurrence, in the previous 12 months." A subset of this indicator was collected in 2018 by Statistics Canada as the sexual assault rate per 100,000 in Canadian CMAs (Statistics Canada, 2022).

The preservation of safety and security is critical to human well-being in cities. There is a growing consensus that crime prevention can be a function of the urban form and that there are critical links between crime prevention and broader sustainable urban development (Cozens, 2002). Relying on the SDG principle "no-one left behind," the target is 0% of the population affected.

4.4. Indicator normalization

The localized SDG indicators were normalized using Min-Max normalization in order to bring all of the indicators onto the same scale from 0 to 1. This method of normalization transforms each indicator value from "0" (representing the lowest achievable value on a scale) and "1" (representing the highest achievable value on a scale). In order to track the progress of CMAs toward the SDG target, the "1" value indicates the target for each indicator and the "0" value indicates the value for the CMA that is farthest from achieving the SDG target (for each SDG indicator included in the scale).

4.5. Indicator aggregation

4.5.1. Arithmetic mean

This is a simple average of the SDG indicator values for each CMAs. In other words, the sum of the normalized SDG indicator values divided by the number of SDG indicators. This average score is easy to interpret but the score also allows CMAs to trade off performance across the SDG indicators. In other words, CMAs with poor performance on one SDG indicator can trade off that performance with strong performances on other SDG indicators. This phenomenon is called compensability and the arithmetic mean offers perfect compensability.

4.5.2. Geometric mean

The geometric mean is calculated by multiplying the normalized indicator scores and then taking the nth root of the product (where n represents the number of normalized SDG indicators included in the scale). The geometric mean allows imperfect compensability in that it is more sensitive to improvements among low indicator scores when compared to shifts in high indicator scores. Given that Geometric means cannot be calculated for any values that are 0, a 1 was added to all values before the Geometric mean was calculated and then 1 was subtracted from the calculated Geometric mean.

TABLE 1 Raw SDG indicators collected for each Census Metropolitan Area.

Localized SDG indicator:	11.1.1	11.2.1	11.3.1	11.6.2	11.7.2
Collection year:	2016	2020	2011	2016	2018
Target:	0	100	1	5	0
Calgary	11.3%	88.9	0.9*	5.2	70.78
Edmonton	12.3%	82.7	1.5	6.4	85.57
Halifax	13.7%	70.9	2.9	5.0	163.3
Hamilton	13.0%	81.1	2.2	7.8	84.7
Kitchener–Cambridge–Waterloo	11.4%	86.2	1.2	7.3	84.78
London	13.9%	77.7	2.1	6.8	81.69
Montréal	10.9%	91.6	2.4	7.1	63.55
Quebec City	7.2%	83.1	2.4	8.2	57.12
Regina	13.3%	90.4	2.2	8.1	84.37
Saskatoon	11.8%	82.6	1.8	6.8	102.37
Sherbrooke	7.2%	76.4	3.5	5.0	74.54
St. Catharines–Niagara	13.9%	80.9	4.1	6.9	75.77
St. John's	11.5%	59.9	2.8	5.1	66.25
Toronto	19.1%	93	1.1	7.0	59.61
Vancouver	17.6%	92.7	0.9*	4.5*	52.28
Victoria	14.2%	90.4	1.2	4.3*	71.27
Windsor	11.7%	67.1	4.0	8.3	66.33
Winnipeg	12.1%	88.2	2.1	5.8	99.18

11.1.1: Proportion of households in core housing need.
11.2.1: Percentage of population <500 meters from public transit access point.
11.3.1: Ratio of land consumption rate to population growth rate (1971–2011).
11.6.2: Average annual fine particulate matter concentrations (PM 2.5).
11.7.2: Sexual assault (rate per 100,000 population).
*These values were replaced by the indicator target value during normalization calculations.

4.5.3. Condorcet ranking

The Condorcet method ranks CMAs according to the extent to which each CMA wins or losses the majority of head-to-head comparisons with other CMAs. This method is more difficult to interpret but it does not allow CMAs to trade-off performance. In other words, the Condorcet method is perfectly non-compensable. The Condorcet ranking was carried out using the votesys R package. As with other Condorcet ranking calculations, there is the possibility to multi-way ties.

5. Results

The raw SDG indicator achievement, according to the targets set in this investigation, varied substantially across the CMAs included in this investigation (Table 1). While none of the selected CMAs achieved the targets set for 11.1.1 and 11.2.1, two CMAs (Calgary and Vancouver) achieved the target set for 11.3.1 (a ratio of land consumption rate to population growth rate that is equal to 1) and Halifax, Sherbrooke, Vancouver, and Victoria achieved the target set for 11.6.2 (an average annual fine particulate matter concentration of 5 ug/m3).

Once normalized, the SDG indicator scores achieved by the selected CMAs reveal further details regarding the heterogeneity of SDG achievement across the CMAs (Table 2). Relative to the other CMAs included in the analysis, on SDG 11.1.1, the highest score (62% progress toward the target) was shared by Quebec City and Sherbrooke while the lowest score was observed in Toronto. Montreal received the highest score (79%) on SDG 11.2.1 while St. John's received the lowest score on this indicator relative to the other CMAs. While Calgary and Vancouver achieved the target set for SDG 11.3.1, the lowest score was achieved by St. Catharines-Niagara (followed closely by Windsor). Halifax, Sherbrooke, Vancouver, and Victoria achieved the target set for 11.6.2 while Windsor received the lowest score on this indicator relative to the other CMAs included in this analysis. Finally, the highest score on SDG 11.7.2 was received by Vancouver (68%) while the lowest score was received by Halifax relative to the CMAs included in this investigation.

As is evident from the previous table, there is a considerable range in performance on the SDG indicators across the included CMAs. Figure 2 provides an example of the relative performance of CMAs via a Leader-Laggard chart demonstrating the range of

TABLE 2 Normalized scores of SDG indicator achievement across Census Metropolitan Areas.

Census Metropolitan Area	11.1.1	11.2.1	11.3.1	11.6.2	11.7.2
Calgary	41%	72%	100%	94%	57%
Edmonton	36%	57%	84%	58%	48%
Halifax	28%	27%	40%	100%	0%
Hamilton	32%	53%	60%	15%	48%
Kitchener–Cambridge–Waterloo	40%	66%	92%	30%	48%
London	27%	44%	65%	45%	50%
Montréal	43%	79%	54%	36%	61%
Quebec City	62%	58%	56%	3%	65%
Regina	30%	76%	60%	6%	48%
Saskatoon	38%	57%	73%	45%	37%
Sherbrooke	62%	41%	21%	100%	54%
St. Catharines–Niagara	27%	52%	0%	42%	54%
St. John's	40%	0%	42%	97%	59%
Toronto	0%	83%	97%	39%	63%
Vancouver	8%	82%	100%	100%	68%
Victoria	26%	76%	93%	100%	56%
Windsor	39%	18%	4%	0%	59%
Winnipeg	37%	71%	65%	76%	39%

11.1.1: Proportion of households in core housing need.
11.2.1: Percentage of population <500 meters from public transit access point.
11.3.1: Ratio of land consumption rate to population growth rate (1971–2011).
11.6.2: Average annual fine particulate matter concentrations (PM 2.5).
11.7.2: Sexual assault (rate per 100,000 population).

performance across all included CMAs in the analysis (the min and max values represented in each bar of the chart) as well as the relative performance of the Kitchener-Cambridge-Waterloo CMA relative to this performance (the black line positioned within each bar in the chart). This chart demonstrates the heterogeneity in the success of the selected CMAs in reaching their target (1) in each indicator (only the targets for SDG 11.3.1 and SDG 11.6.2 were achieved) as well as the heterogeneity exemplified by the Kitchener-Cambridge-Waterloo CMA (the CMA only came close to achieving the target for SDG 11.3.1).

When these normalized scores were aggregated into index rankings, some interesting patterns began to emerge (Table 3). First, the ranking of CMAs between the Arithmetic and Geometric ranking calculations did not vary substantially (although there are examples of CMAs that made dramatic movements between these rankings, as observed in the case of Toronto which fell 4 spots between the two calculations). Greater deviations were observed when comparing the arithmetic and geometric ranking procedures against the Condorcet ranking procedure. As an example, Montreal (which ranked 10 and 13 according to the arithmetic and geometric ranking procedures respectively) fell to the lowest ranking in the Condorcet ranking procedure. Alternatively, Toronto, Vancouver, Kitchener-Cambridge-Waterloo, and Sherbrooke all experienced significant gains in their rankings under the Condorcet ranking procedure. As with other Condorcet ranking calculations, there is the possibility to multi-way ties. In these instances—such as with Quebec City, St. John's and Winnipeg—the average between all tied ranks was assigned to all cities equally.

When the mean arithmetic and geometric values are provided for each CMA according to their Condorcet ranking, the disconnect between these ranking procedures becomes more apparent (Table 4). While Toronto received middling arithmetic and geometric means, the CMA still ranked in the top 3 according to the Condorcet rankings. Similarly, while Montreal actually received very similar arithmetic and geometric mean scores to Toronto, the CMA was ranked at the bottom in the Condorcet ranking procedure. The differentiation of these storylines highlights the differential compensability of these ranking procedures, where Condorcet rankings do not allow for performance to be traded off across the indicators.

6. Discussion

This investigation demonstrated how trade-offs, inherent in weak vs. strong sustainability conceptualizations of sustainable development, can create significant differences in the monitoring and evaluation of sustainable development. Allowing goals to be traded off, theoretically premised on weak sustainability and methodologically implemented via simple arithmetic means for indicator aggregation, will portray a significantly different set of outcomes when compared to non-compensable aggregation

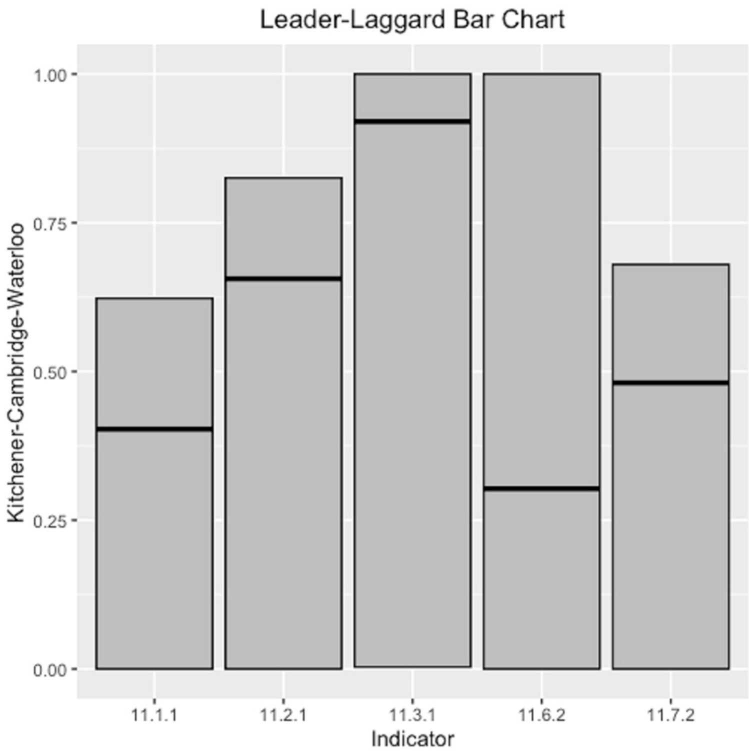

FIGURE 2
Leader-Laggard Bar Chart of Kitchener-Cambridge-Waterloo CMA performance on Normalized SDG Indicators.

methods premised on notions of strong sustainability. Given the significant heterogeneity of Canadian cities in the achievement of SDG 11 indicators, these differences can result in either masking or skewing sustainability challenges, leaving municipal strategic plans meant to address those sustainability challenges open to political manipulation.

Even as the 2030 deadline looms for the Sustainable Development Goals, the concept of sustainability and sustainable development still faces challenges of understanding and measurement. The translation of sustainability into policy can be biased by narrow interpretations of sustainability targets and hampered by limited operational capacity. The operational challenge of sustainability aggravates further by the fact that the measurement of sustainable development relies on both paths followed (economic policies) and outcomes (poverty) (Sachs et al., 2017). The normative approach to sustainability helps to set a universal approach to the foundation of the concept and determine appropriate means to achieve objectives.

It is generally recognized that sustainable development requires assessing actions and outcomes from three dimensions: society, economy, and the environment. People may adopt different paths or arrive at diverse conclusions due to changes in perspectives and temporal objectives. Therefore, a normative agreement on greater interests and scientifically acceptable methods to measure outcomes are inevitable to progress toward common agenda. Meadows (1998) was convinced of the necessity of the inclusion of a broader set of indicators and following a continuous learning process to find an adequate and effective methodology to measure them. Competing priorities and subsequent trade-offs are well recognized while setting a sustainability agenda (Pörtner et al., 2022; Rockström et al., 2023). However, a theoretically appropriate means of measurement is crucial for informed decision-making (Nardo et al., 2005).

Methodological challenges faced by urban sustainability indicators are technical and conceptual. Technical issues include normalization, weighting, and aggregation, whereas conceptual challenges revolve around ambiguities due to dimensional heterogeneity, operational jurisdiction, and strong vs. weak sustainability (Huang et al., 2015). The debate of weak and strong sustainability is about the degree of substitutability of natural resources with manufactured capital, and the role of technology as a solution in sustainable development (Daly, 1990; Ekins et al., 2003; Dietz and Neumayer, 2007). Sustainability indicators are used to assign limits and targets and measure human actions from all three dimensions (society, economy, and environment) and assertion of normative perspective: weak and strong sustainability (Meadows, 1998). For instance, SDGs incorporate multiple sustainability dimensions, if equal weightage is adopted for the aggregation of variables it promotes a weak sustainability perspective (Huang et al., 2015). Within this context, the application of strong and weak sustainable development in municipal governance is a challenge because it is premised on the way in which the various pillars of sustainable development are valued (and a recognition of how current trade-offs could impact

TABLE 3 Arithmetic, geometric and Condorcet rankings of CMA SDG achievement (Sorted by Condorcet ranking).

Census Metropolitan Area	Arithmetic ranking	Geometric ranking	Condorcet ranking
Vancouver	17	16	18
Calgary	18	18	17
Toronto	14	10	16
Victoria	16	17	15
Kitchener–Cambridge–Waterloo	11	12	13.5
Sherbrooke	12	11	13.5
Quebec City	15	15	11
St. John's	8	8	11
Winnipeg	7	6	11
Edmonton	13	14	9
Saskatoon	9	9	8
Regina	5	5	7
London	6	7	6
Hamilton	4	4	5
Halifax	3	3	4
St. Catharines–Niagara	2	2	2.5
Windsor	1	1	2.5
Montréal	10	13	1

future opportunities). One option for addressing this tension may be via the use of futures thinking methods like scenario planning where, instead of forecasting the possible outcomes of current trade-off decisions, municipalities begin with the preferred future scenario and then backcast to the present in order to identify the various policy avenues that could be followed to achieve that future (and identify the trade-offs that would be allowed among those possible avenues).

The performance rankings displayed in a SDG index are defined by the weighting and aggregation of the indicators in the index. The relative ranking has important implications due to different weightings based on circumstantial relevance (Booysen, 2002). Likewise, the aggregation of different variables by allowing a simple substitution can have an important implication on ranking cities and countries (Rickets et al., 2014). Ignoring compound changes in various goals would allow a loss in one indicator offset by a gain in another variable. For instance, arithmetic mean allows a perfect substitution without limits which tends to take a path of weak sustainability (Rickets et al., 2014; Sachs et al., 2017). Whereas, strong sustainability occurs when indicators are not substitutable, as we have seen in the case of the Condorcet method.

The United Nations emphasize treating all goals equally. Under conditions where indicator performance could be traded off, as in the case of compensable aggregation methods like the arithmetic mean, the equal weighting of indicator performance could allow cities to engage in unsustainable methods for boosting economic and social wellbeing. For example, if a city could generate sufficiently strong performances on measures of social and economic development, that city may be able to conceal a poor performance on climate action in their aggregate score or ranking (when indicators are equally weighted and aggregated using an arithmetic mean). In this case, the index would have little utility in exposing unsustainable practices and motivating effective policies in favor of sustainable development (Sachs et al., 2017).

7. Conclusion

There was considerable variation in SDG target achievement across the CMAs included in this analysis. Only the targets set for SDG 11.3.1 (a ratio of land consumption rate to population growth rate that is equal to 1) and 11.6.2 (an average annual fine particulate matter concentration of 5 ug/m3) were achieved by the CMAs included in this investigation. When the normalized scores were aggregated into rankings, the performance of these CMAs across the rankings varied substantially. While Calgary received the top ranking under the Geometric and Arithmetic ranking procedure, Vancouver received the top ranking via Condorcet rankings. Similarly, while Windsor received the lowest ranking according to the Geometric and Arithmetic ranking procedures, Montreal received the lowest ranking via the Condorcet ranking procedure. Given the relative compensability of these ranking procedures (Arithmetic means allowing perfect compensability while Condorcet ranking do not allow compensability), the differences observed between these ranking procedures highlight how the trade-off of achievement across domains of sustainability can impact sustainable development among Canadian cities.

TABLE 4 Comparison of arithmetic and arithmetic means of CMA SDG achievement by Condorcet rankings.

Census Metropolitan Area	Arithmetic mean	Geometric mean	Condorcet ranking
Vancouver	0.72	0.67	18
Calgary	0.73	0.71	17
Toronto	0.57	0.52	16
Victoria	0.70	0.68	15
Kitchener–Cambridge–Waterloo	0.55	0.54	13.5
Sherbrooke	0.56	0.54	13.5
Quebec City	0.49	0.47	11
St. John's	0.48	0.44	11
Winnipeg	0.58	0.57	11
Edmonton	0.56	0.56	9
Saskatoon	0.50	0.50	8
Regina	0.44	0.42	7
London	0.46	0.46	6
Hamilton	0.42	0.41	5
Halifax	0.39	0.36	4
St. Catharines–Niagara	0.35	0.34	2.5
Windsor	0.24	0.22	2.5
Montréal	0.55	0.54	1

These findings need to be interpreted according to the limitations of this study. Given the scale of the indicators at the federal-level, the localization of these indicators at the municipal-level involved a re-interpretation of those indicators. This process was heavily informed by the availability of municipal indicators from Statistics Canada that could align with the SDG indicators set in the original indicator framework. Furthermore, the heterogeneous availability of indicators across municipalities shifted the scale of the investigation to Census Metropolitan Areas and reduced the number of cases that could be included in this investigation. As a result, further statistical analysis was not reliably feasible beyond the comparisons of the aggregation methods presented here. Together, these limitations note the continued need to carefully address data gaps in SDG measurement and localization within cities. Future research can apply a similar approach to other goals and targets corresponding to the SDG 11 targets in the city domain.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.statcan.gc.ca/en/start.

Ethics statement

This study has been reviewed and received ethics clearance through the University of Waterloo Research Ethics Committee (ORE #41177).

Author contributions

MR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing—original draft, Writing—review & editing. CM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing—review & editing. JS: Data curation, Formal analysis, Software, Writing—review & editing. BF: Funding acquisition, Project administration, Resources, Validation, Writing—review & editing. JW: Investigation, Project administration, Supervision, Validation, Writing—review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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