

Orienteering the landscape of urban water sustainability indicators^{☆,☆☆}

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ABSTRACT

Indicator frameworks for urban water sustainability are very diverse, with tools designed for different practical use cases and employing different assessment approaches. This creates a complex landscape that scholars and practitioners must successfully “orienteer” so that they may effectively apply the literature to develop theory and/or manage practical problems of sustainability. Based on a systematic analysis of indicator frameworks for urban water sustainability, this paper presents an overview of framework designs and current design trends. Five key framework design decisions and respective options are outlined, and the patterns in and implications of their use are discussed. While the decisions were identified based on material for assessing urban water sustainability, the categories of decisions and options are relevant to environmental sustainability more broadly. The paper is aimed at framework users looking for an overview of different framework designs and their benefits and drawbacks and framework designers interested in common options, current trends, and difficulties.

1. Introduction

Sustainability assessment is a class of analytical tools designed to help decision-makers find actions that make society more sustainable (Kates et al., 2001). The intended benefits of assessments are numerous and far reaching. They are expected to supply information needed for fact-based decision-making, provide forums for debate and deliberation, and enhance social learning (Mitchell et al., 2006). Sustainability assessments provide a vision of a sustainable society; this provides a compass and a map for societies to monitor progress towards sustainability goals and identify barriers along the way and allows users to identify the advantages and disadvantages of different policy options. Among varied types of sustainability assessment that are available, indicators and indices designed for cities have gained in popularity (e.g., Rosales, 2011; Mori and Christodoulou, 2012).

Extensive efforts in designing sustainability indicators have resulted in a large body of frameworks (e.g., da Silva et al., 2019; Gonzalez-Garcia et al., 2018; Milman and Short, 2008). The resultant set of indicators is very diverse, with tools designed for different practical cases and employing different measurements. This heterogeneity makes

it difficult to make sense of all the available frameworks, their similarities and differences, and transferability to other cases. And yet, systematic comparison of frameworks is essential to develop improved sustainability assessments that provide more accurate and robust understandings of current sustainability challenges and the potential solutions. Identifying methods of comparing and contrasting indicator systems is therefore an important challenge within the field of sustainability science.

Engaging with this literature is much like orienteering a complex physical landscape of mountains, valleys, forests, and rivers. “Orienteering” is the skill of finding one’s way through such complex landscapes (Kjellström, 1994). Successful orienteering requires three things: Knowing one’s destination, having a map that describes the landscape and reveals possible paths to the destination, and a compass to locate oneself and to set upon the correct path. An individual may engage in the sustainability indicators literature for many reasons, including theoretical motivations (e.g., understand the factors that drive sustainability), practical reasons (e.g., assess progress towards sustainability in a particular region), or a mixture of theoretical and problem-oriented motivations. In any case, map and compass are required—we need

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tools to make sense of the myriad sustainability indicators that are available, and to identify aspects of these indicators that are relevant to a particular end-use. The literature on sustainability indicators is vast and vibrant, and this includes many recent efforts to “fill in the map” of sustainability indicators (Chopin et al., 2021; Orozco-Messana et al., 2021; Sharifi et al., 2021; Sharifi, 2021; St Flour and Bokhoree, 2021; Valizadeh et al., 2022). At the same time, however, more work is needed to gain a clear landscape view of this literature.

This paper advances our understanding of the sustainability indicators landscape through the use of qualitative comparative analysis to review and compare sustainability frameworks in terms of their key underlying dimensions, which may then be used to systematically compare and contrast frameworks. This review is aimed at two audiences. First, it provides *framework users* a summary of different framework designs and their benefits and drawbacks. This can support them in finding a tool that aligns with their needs. Second, *framework designers* benefit from an overview of common options, current trends, and difficulties. This can assist in a systematic reflection of the challenges and opportunities of different designs of indicator systems.

In this paper we focus specifically on urban water sustainability, which is one critical subdomain of sustainability and an area where many nations, regions, and cities have developed indicator frameworks. We chose water as a focus because it is a top ten global sustainability challenge (World Economic Forum, 2019) and a leading issue for cities (McDonald et al., 2011). However, we expect the insights gained from this analysis to apply to other areas of environmental sustainability.

The analysis consists of two main parts. The first part focuses on design decisions. In its broadest sense, design refers to the overall strategy employed to evaluate the performance of a city and contribute to foster sustainability. The design reflects decisions about goals, measures of sustainability performance, and reporting strategy, among others. The heterogeneity in tools is in large part a result of different choices during the design process. Authors select different goals, different measures, and different reporting strategies. Based on our

analysis, we outline five key decisions and common choices. The second part focuses on trends. The type of options that authors select and the way they combine these show certain patterns. These patterns or trends have consequences for the use of single frameworks as well as the overall body of frameworks. The second part discusses different trends and their implications. This review purposefully omits questions of measurement (e.g., weighting of indicators). These tend to be highly technical and are discussed in detail elsewhere (Juwana et al., 2012). Next, we first introduce our corpus of indicator frameworks and analytic approach before discussing the design decisions and trends.

2. Corpus and methodological approach

Our approach to orienteering this complex landscape of indicator systems is summarized in Fig. 1, below. Systematic Web searches were used to generate an initial sample of assessments focused on urban sustainability. The sampling process was intended to generate as diverse a group of assessments as possible; thus a broad range of sources were included in terms of outlets, geographic area, as well as academic versus non-academic sources.

This initial group of documents – which we refer to as the “corpus” of sustainability indicator frameworks – is further augmented using citation analysis and snowball sampling. This means that additional assessments included in sampled documents were also added to the corpus. Since our analysis depends on the categorization of content extracted from these documents, it was necessary to stop building the corpus once a set of about 30 documents were identified. This is because each document would yield ten or more content elements to be included in the analysis; therefore, keeping the corpus relatively small is important to ensure the analysis is manageable.

The most important consideration with the corpus is not its overall size, but rather its diversity. Indeed, the final corpus includes peer-reviewed journal articles, empirical studies, conference papers, reports, score-cards, and reporting frameworks published by academics,

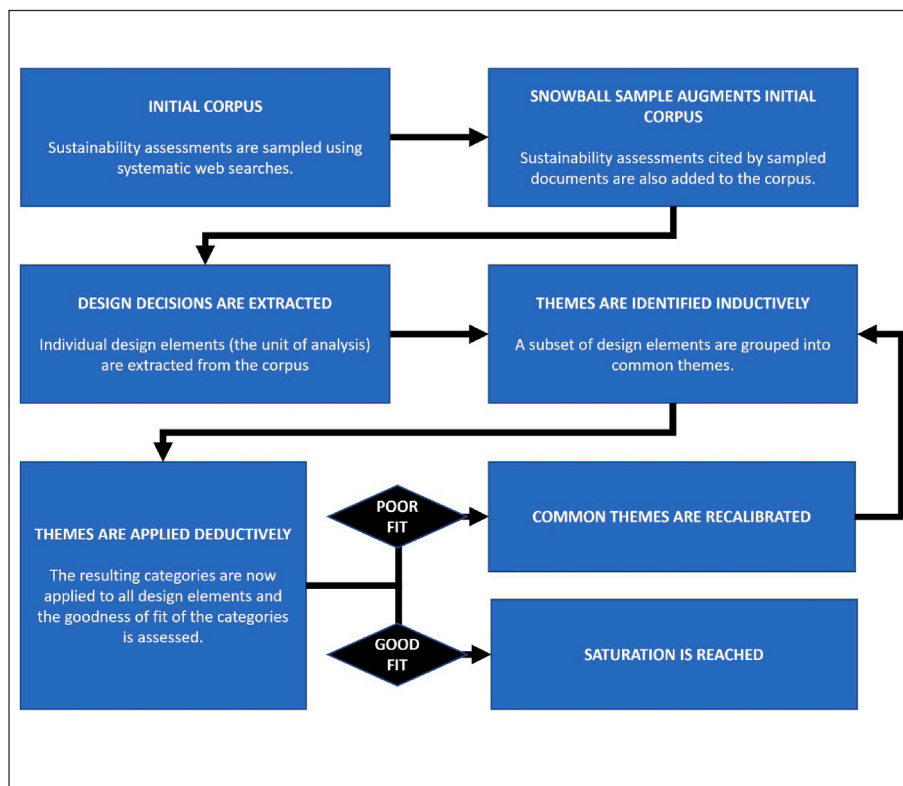


Fig. 1. Overview of empirical procedure.

Table 1
Corpus of water sustainability indicator frameworks.

Author(s)	Year	Country/Geographic region ^a	Framework name (if applicable)	Publication title
Arcadis	2016	Global (50 cities)	Sustainable Cities Water Index	Sustainable Cities Water Index. Which cities are best placed to harness water for future success?
Ashley et al.	2003	United Kingdom		Sustainable decision making for the UK water industry
Beck et al.	2016	Australia Asia-Pacific	Water Sensitive Cities Index	Beyond benchmarking: a water sensitive cities index
Chesterfield et al.	2016	Australia South-East Asia	Water Sensitive Cities Index	A Water Sensitive Cities Index— Benchmarking cities in developed and developing countries
Rogers et al.	2020	Global with a focus on Australia	Water Sensitive Cities Index	Water Sensitive Cities Index: A diagnostic tool to assess water sensitivity and guide management actions
De Carvalho, Carden, & Armitage	2009	South Africa Mozambique		Application of a sustainability index for integrated urban water management in Southern African cities: Case study comparison— Maputo and Hermanus
Feingold, Koop, & van Leeuwen	2018	United States	City Blueprint	The City Blueprint approach: urban water management and governance in cities in the US
van Leeuwen, & Sjerps	2015	Netherlands	City Blueprint	The City Blueprint of Amsterdam: an assessment of integrated water resources management in the capital of the Netherlands
van Leeuwen et al.	2012	Netherlands	City Blueprint	City blueprints: 24 indicators to assess the sustainability of the urban water cycle
van Leeuwen et al.	2016	World (45 cities, mostly in Europe)	City Blueprint	City Blueprints: baseline assessments of water management and climate change in 45 cities
Koop & van Leeuwen	2015	World (45 cities/ regions)	City Blueprint	Assessment of the sustainability of water resources management: a critical review of the city blueprint approach
Foxon et al.	2002	United Kingdom		Sustainability criteria for decision support in the UK water industry
Government of Canada	2007	Canada	Canadian Water Sustainability Index	Canadian Water Sustainability Index (CWSI). Project Report
Hellström, Jeppsson, & Kärman	2000	Sweden		A framework for systems analysis of sustainable urban water management
Kay	2000	Israel		Measuring sustainability in Israel's water system
Texas Living Waters Project	2016	United States	Texas Water Conservation Scorecard	Texas Water Conservation Scorecard
Kramer, Walker, & Redmond	2017	United States	Texas Water Conservation Scorecard	Evaluating water utilities: The Texas Water Conservation Scorecard
Lundin & Morrison	2002	South Africa Sweden		A life cycle assessment based procedure for development of environmental sustainability indicators for urban water systems
Lundin, Molander, & Morrison	1999	Sweden		A set of indicators for the assessment of temporal variations in the sustainability of sanitary systems
Milman & Short	2008	Czech Republic El Salvador Mexico		Incorporating resilience into sustainability indicators: An example for the urban water sector
OECD	2018a	Global (12 cities)	OECD Water Governance Indicator Framework	Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices
OECD	2018b	Global	OECD Water Governance Indicator Framework	OECD Water Governance Indicator Framework
Pakzad & Osmond	2016			Developing a sustainability indicator set for measuring green infrastructure performance
Ries, Trotz, & Vairavamoorthy	2016	United States		Fit-for-Purpose' sustainability index: a simplified approach for US water utility sustainability assessment
Shilling et al.	2014	United States	California Water sustainability Indicators Framework	The California Water sustainability Indicators Framework
Sun et al.	2016	China (Inner Mongolia)		Sustainability assessment of regional water resources under the DPSIR framework
Sundberg, Svensson, & Söderberg	2004			Re-framing the assessment of sustainable stormwater systems
Sydney Water	2011	Australia		Annual Report 2011
van Ginkel et al.	2018	World (10 cities)	Urban Water Security Dashboard	Urban Water Security Dashboard: systems approach to characterizing the water security of cities
Western Resource Advocates	2010	United States		Arizona Water Meter. A comparison of water conservation programs in 15 Arizona communities
Xu, Bin, & Xu	2019	China		Assessment of Water Resources Sustainability in Mainland China in Terms of Water Intensity and Efficiency

^a Note: Some indicator frameworks were applied to cities, pretested on cities, or developed in collaboration with stakeholders. The country/geographic region indicates where the respective cities are located.

consulting firms, water providers, public agencies, and water professionals and covers a wide geographic spectrum including the United States, Australia, Israel, Canada, Mexico, Sweden, the Netherlands, the United Kingdom, South Africa, Mozambique, and Inner Mongolia. Table 1 provides an overview of the final corpus.

The following sections provide greater detail on the research procedures outlined in Fig. 1. Once the corpus was identified, the process includes two main parts: 1) the extraction of “design elements” from the documents in the corpus, and 2) the thematic sorted of these elements into a set of design “decisions” and “options” using qualitative content

analysis (Brown and Clarke, 2006).

2.1. Identification of design elements

In the first step, we selected a subset of 20 documents and conducted an exploratory analysis. We extracted all passages in the documents that relate to “design elements” of the associated sustainability assessment. The term “design element” is intentionally broad and refers to two main categories of statements. The first is a “design decision,” which refers to any unique feature of the assessment, including the assessment's

purpose, reported outcomes, variables measured, and theories used. The second is a “design option,” which represents a possible option for the associated design decision.

To make sense of what design elements are, and the role they play in the structure of a sustainability indicator framework, we can think of the design of an indicator framework similar to how we think of the design of a car. When designing a car, car makers make many decisions. They, for example, decide on a body style with options being sedan, minivan, and station wagon and on a fuel type with options being gas, electric, and hybrid. We can use these decisions and options to describe and compare cars (e.g., a gas powered minivan vs. a hybrid sedan vs. a gas powered sedan)?

Our analysis is focused on the inductive identification of all those design decisions and corresponding options that allow for a complete description of any given sustainability assessment. Once completed, the coding resulted in approximately 400 segments of text ranging in length from one sentence to multiple paragraphs in length.

2.2. Thematic sorting of design decisions and options

Following the extraction of design elements, the decisions and options evident in the extracted segments of text were then sorted thematically. This yielded an initial typology of five core decisions that are relevant to all or a vast majority of frameworks in the initial subset. In the second phase, this initial typology was used as a framework for a quasi-deductive analysis meaning that we “tested” and refined the identified decisions on the remaining documents in the corpus (see also Bergman et al., 2017).

As we progressed through the remaining documents, less refinement to the typology was required. This indicated that saturation was reached and further data collection was unnecessary (Saunders et al., 2018; Morse, 1995; Lincoln and Guba 1985). It is important to note that our unit of analysis were design decisions rather than entire indicator frameworks. The goal was to identify key decisions along which the frameworks are similar or different. The frameworks in our corpus show frequent but limited overlap. For example, two frameworks may pursue the same goal and employ the same data collection method but may differ in how they report the results. For these reasons, it is impractical to classify approaches as a whole. Instead, our analysis focuses on systematizing frameworks in terms of the major decisions and the options associated with each decision. The resulting typology provides an overview of design choices and allows users to characterize and compare frameworks.

3. Results: design decisions and options

The analysis yielded five core design decisions evident in the corpus. For each decision, we find different options. The goal of a framework, for example, may consist in benchmarking cities, providing information for decision-making, or facilitating learning. Table 2 provides an overview of these questions and the options. In the following, we discuss each design decision and its options separately before discussing general trends.

3.1. Goals: what is the purpose of the framework?

The first decision relates to the objective of the framework. Indicator frameworks are used to achieve a variety of goals. For example, frameworks can provide information to guide policy making or they can provide a performance overview for investors. Goals such as these are closely tied to intended use cases—i.e., policy making vs. investment decision—and user groups—i.e., policy makers vs. investors. As such, goals delineate who can benefit from using the framework and in what situation. Based on our analyses, we can broadly distinguish four main goals, or decision options, in this category. These include benchmarking, informing action, learning, and collaboration.

Benchmarking aims to determine the status quo of a city’s water sustainability, monitor progress in achieving sustainability goals, and compare different places in terms of their performance. These frameworks can be designed for a specific stakeholder group and a specific use case. However, more often, they are aimed at a broad array of stakeholders including businesses, investors, non-governmental organizations, current and prospective residents, and the general public. Benchmarking tools often fulfill communicative purposes. They inform stakeholders about the current stage of or change in a city’s water sustainability. They can serve as a marketing tool in the international competition between cities or a means to legitimate action. Illustrative examples of benchmarking tools are:

The Arcadis Sustainable Water Index assesses 50 global cities by the stewardship of their water across issues impacting their water resiliency, efficiency and quality to show which cities are best positioned to harness water for their long term success. (Arcadis, 2016, p.4)

It was also suggested that CWSI [Canadian Water Sustainability Index] could be used as a communications tool to verify or discredit existing speculation in the community on a number of water issues, particularly around quality and quantity. Results can also be used to market the community’s potential to prospective developers and industries, especially water-intensive industries. (Government of Canada, 2007, p.23)

Frameworks focusing on *informing action* provide insights for policy making, decision making, and planning. They focus on evaluating known challenges or identifying unrecognized challenges. This often involves a future-oriented look in that current data are used to estimate future developments. They may also provide insights into the effectiveness of current strategies. Illustrative examples are the Water Sensitive Cities Index and the Water Provision Resilience Indicator:

The WSC [Water Sensitive Cities] Index is designed to facilitate assessment of the water sensitivity of a local municipality or metropolitan city, set targets based on the best available research and inform management responses to improve water sensitive

Table 2
Design decisions and options.

Decision	Options
Goals:What is the purpose of the framework?	<ul style="list-style-type: none"> • Benchmarking • Informing action • Learning • Collective action
Sustainability factors:What does the framework measure?	Types of factors: <ul style="list-style-type: none"> • Goals • Actions • Context (i.e., facilitating/inhibiting social/natural system factors) Selection of factors: <ul style="list-style-type: none"> • Literature reviews • Theory-driven approaches • Expert consultations • Data-driven approaches • Refinement based on pre-tests
Performance:How does the framework assess performance?	<ul style="list-style-type: none"> • Performance as distance to end-goal • Performance as positive change over time (sustainability as a desirable direction of development) • Performance as better/worse rank in cohort of peers (sustainability as a comparative attribute) • Performance as making the right choices (sustainability as a choice)
Data:What data does the framework use?	<ul style="list-style-type: none"> • Existing data • Stakeholder input
Outcomes:How does the framework summarize the assessment?	<ul style="list-style-type: none"> • Overall score • Composite indices • Case studies • City typologies

practices. This paper presents results from a pilot study application of the WSC Index, demonstrating the value of the WSC Index as a tool to equip stakeholders with the capacity to monitor, evaluate and ultimately improve their water system practices through the identification and prioritization of management responses. (Chesterfield et al., 2016, p.1)

The Water Provision Resilience indicator provides a means of approximating the ability of a city or water provider to maintain and increase the portion of the population with access to safe water. The indicator provides information regarding aspects of the water supply system and its management that make the system more vulnerable to stresses. Such information can aid managers in prioritizing the creation of policy or programs to increase the long-term resilience of the system. (Milman and Short, 2008, p.766)

Learning objectives are manifold. They include inter-city learning, city and stakeholder education, and knowledge generation. Educational aims employ frameworks as an intermediary tool to identify leaders, best practices, and success stories useful to cities who aim to improve their performance as well as to raise awareness among stakeholders. This also includes gaining a better understanding of complex systems, which can eventually lead to improved city responses. Here are two examples:

The CBF [City Blueprint Framework] is essential to show the potential gain possible by sharing knowledge, experiences and best practices amongst cities. Moreover, it more accurately depicts the own activities and efforts of cities to improve the sustainability of their IWRM [Integrated Water Resource Management] and how they can alleviate environmental pressures such as emissions of poorly treated wastewater and solid waste. (Koop and van Leeuwen, 2015, p.5662)

Evaluating indicators provide a periodic or continuous stream of several types of information. This information contributes to building knowledge about how systems work, how they are changing, how they might change, and what we can do to ensure or build sustainability in these systems. One type of contribution is improved knowledge about the functioning of usually-complex systems by the public and decision-makers. (Shilling et al., 2014, p.123)

Finally, *collaboration* refers to the use of indicator frameworks as a vehicle to bring together stakeholders and create lasting partnerships and cohesive groups. Approaches pursuing this objective understand collaboration as a central component of promoting action and creating interventions. They conceptualize the assessment as a collective endeavor encompassing different stakeholders. This commonly involves a bottom-up or hybrid approach, wherein an informed public actively contributes to sustainability solutions (for a detailed discussion see also Pivo et al., 2020). An example is the OECD Water Governance Indicator Framework:

The indicator framework does not serve as a monitoring tool to investigate progress against a defined framework. It is also not intended to provide benchmarking across countries, basins, regions and cities, as according to the OECD Principles, governance responses are highly contextual and hardly comparable. Its primary objective is to stimulate a dialogue across stakeholders on what works, what does not, and what should be improved. (OECD, 2018, p.50)

These goals are not mutually exclusive. An indicator framework may pursue only one or several of these goals. In fact, a majority of the frameworks in our corpus list multiple of these objectives. The index developed by Beck et al. (2016,p.1), for example, aims to “support strategic planning and decision-making; foster inter-city learning and collaboration; and enable national governments to assess their cities’ urban water management trajectories in relation to other cities.” Such multi-functionality is often associated with efficient resource use and

broader impact. However, since goals are closely related to intended use cases and user groups, the simultaneous pursuit of multiple goals may also result in a lack of focus.

3.2. Sustainability factors: What does the framework measure?

Urban water sustainability is a broad concept that involves a variety of factors. The term “factors” here refers to any aspect that impacts or is impacted by sustainable water management such as water stress, reservoir size, and water quality. Given the breadth and diversity of factors, it is hardly possible to measure them all and frameworks therefore include subsets of factors. Identification and selection of factors is a non-trivial task. The frameworks in our corpus report different strategies to tackle this challenge. Most prominent are literature reviews, theory-driven factor definition, stakeholder or expert consultations, and data-driven approaches.

Literature reviews determine factors based on previous work, especially existing indicator frameworks. Due to the popularity of this strategy, literature reviews tend to be presented as generic approach without further explanation. Milman and Short (2008, p.761), for example, state that as a beginning, they “conducted an extensive review of the literature on water supply sustainability, water system indicators, and resilience.” The insights gained from this literature review in combination with personal experience were then used to define six aspects of urban water supply systems (ibid).

Theory-driven approaches determine factors based on established concepts. The theories referenced in our material include the Pressures-States-Response framework and its extensions (e.g., Milman and Short, 2008; van Ginkel et al., 2018; Sun et al., 2016), the pillars of sustainability and its extensions (e.g., Foxon et al., 2002; De Carvalho, Carden and Armitage, 2009), systems theory (e.g., Sundberg et al., 2004), the life-cycle-assessment framework (e.g., Lundin and Morrison, 2002), the ecosystem services theory (e.g., Pakzad and Osmond, 2016), the water footprint concept, the urban metabolism concept, and the ecosystem services concept (e.g., van Leeuwen et al., 2012).

Theories differ in their foci and conceptualization of problems and solutions and therefore serve different purposes. The Pressure-State-Response framework, for example, is a prominent choice for assessing environmental threats with established causal logic, even though it is rarely used to diagnose organizational complexities with many “unknowns” (see also Kelly, 1998; Niemeijer and de Groot, 2008; Verma & Raghubanshi, 2018).

Stakeholder or expert consultations draw from the knowledge and experience of people involved in water management to arrive at a set of factors. This approach is based on the assumption that stakeholders, often practitioners, best understand the characteristics of successful water management. Involvement of stakeholders often goes beyond the identification of factors. Stakeholders are treated as partners throughout the evaluation process and involved in various stages such as framework development, goal definition, and selection of indicators.

An illustrative example of expert consultation is the approach taken by Ries et al. (2016, p.38) to identify sustainable practices. The authors first interviewed an external advisory committee of 12 US utility leaders using semi-structured interviews and then surveyed water sector professionals using a free-listing method.

Finally, *data-driven approaches* take a different strategy. Rather than focusing on what should be measured, they focus on what is already measured or could easily be measured given available data. This pragmatic approach emphasizes feasibility and resource efficiency. Data-driven approaches tend to be used as a complementary strategy and are rarely found as a stand-alone technique. The Canadian Water Sustainability Index provides an example of a data-driven approach. For the trial version, “several indicators have been constructed to rely on data collected by federal agencies, such as Statistics Canada and the Water Survey of Canada” (Government of Canada, 2007, p.6).

The initial indicator sets derived from any one or a combination of

these approaches are often refined using pre-tests and case studies. The factors are applied to a relatively small set of cases, or one case, to identify weaknesses and additional assessment needs. Lundin and Morrison (2002), for example, tested and subsequently refined a set of 12 indicators using Göteborg (Sweden) and King William's Town (South Africa) as case studies.

The factors selected based on these strategies are highly diverse. Examples of factors in our corpus are water security, size and growth of a city (van Ginkel et al., 2018, p.1), climate robustness (Feingold et al., 2018), ecosystem health, infrastructure conditions (Government of Canada, 2007, p.1), surface and groundwater quality (van Leeuwen et al., 2012), socio-political capital, livability (Beck et al., 2016, p.4), water conservation (Western Resource Advocates, 2010, p.26), adaptive and sustainable management (Shilling et al., 2014, p.13), and participation and responsibility (Foxon et al., 2002, p.292).

We conducted an inductive analysis on the factors evident in our material, to identify types of factors. This analysis revealed three analytically different types, namely goals, actions, and contextual factors. *Goals* or outcomes refer to the ends sought from sustainable water management. Some outcomes pertain to water system services (e.g. water security, climate robustness), some pertain to adverse operational impacts (e.g. ecosystem health), and some pertain to co-benefits (e.g. livability). *Actions* include strategies that cities undertake to achieve these goals. They include, for example, water conservation, adaptive and sustainable management, and citizen participation. Finally, *contextual factors* encompasses inhibiting factors, i.e., barriers or constraints that prevent cities from achieving their goals, and facilitating factors, i.e., advantages or strengths that support cities in achieving their goals. They can be rooted in the social system (e.g., available resources, public support) or the natural system (e.g., precipitation, hydrology). Examples of contextual factors are socio-political capital (Beck et al., 2016, p.4), social, environmental, and financial characteristics (Koop and van Leeuwen, 2015, p.5653), and size and growth of a city (van Ginkel et al., 2018, p.3).

Factors within these three categories offer complementary insights into performance. Goal-focused factors assess a city relative to desired outcomes. Action-focused factors assess a city in terms of the resources and efforts dedicated toward sustainability purposes. Context-focused factors determine a city's overall positioning for achieving sustainability goals, taking action and adapting as far as needed and as far as possible, given the set of opportunities (e.g., political support) and constraints (e.g., political opposition) in a city's environment. As such, each factor type allows to examine performance from a different perspective. For example, the factor water security (goal) provides information on future availability of water in a city. However, it does not tell us about the reason for good or bad performance. A city may perform well because of good water management or because of water abundance in the region. These aspects are captured by factors of the categories action and context. Given the complementarity, most frameworks combine factors of two or all three categories.

When discussing factors, it is important to mention factor definition. There are considerable differences in the definition and hence use of factors across frameworks. An illustrative example is resilience. Chessterfield et al. (2016, p.4) define resilience as "the capacity to maintain the delivery of water system services as conditions change and in the face of acute and chronic disturbances, through adaptation and/or recovery." In contrast, Kay (2000, p. 619) specifies resilience as "the power of the system to recover after failure occurs; that is, the speed of recovery." Accordingly, indicator frameworks may use similar terms but measure different characteristics of water sustainability. Conceptual clarity is a ubiquitous challenge in the water sustainability literature (Biswas, 2004). While we are not able to tackle this challenge here, it is important to be aware of it.

3.3. Performance: How does the framework assess performance?

Determining sustainability factors is one key characteristics of an indicator framework. Another key characteristic consists in how frameworks define performance relative to these factors. Given these factors, how do we know if a city performs well or poorly? The answer to this question is tied to the underlying conceptualization of sustainability. As Connelly (2007) and Purvis et al. (2019) illustrate, there are different ways in which we can conceptualize sustainability. For example, sustainability can be understood as an end-goal (Milman and Short, 2008) or as a continuous process (Lundin et al., 1999). Accordingly, there are different ways to define progress in water sustainability—e.g., progress can mean approaching an end goal or improvement compared to the previous year.

Based on our material, we can broadly distinguish four conceptualizations of sustainability articulated within indicator frameworks. First, sustainability can be conceptualized as an *endpoint*. The endpoint may be an idealized city, a predefined goal, or the current or a past state. Sustainability is a finite endeavor, which is achieved when the endpoint is reached. Accordingly, progress is measured in terms of the distance to the endpoint. The frameworks proposed by Kay (2000) and Milman and Short (2008) provide examples of endpoint approaches:

A sustainable system should display high reliability, high resiliency, and low vulnerability. Because these indices are defined, directly or indirectly, in relation to some threshold of failure, satisfactory performance is a result of operation of the system within that threshold. If the failure threshold is defined by the annual renewable water resource (a function of the precipitation over the year), failure occurs when total water use exceeds that amount. So, a sustainable system is one that operates, at most times, with demand (or, better, use) below renewable supply. (Kay, 2000, p.619)

Specifically, it takes into consideration how water supplies, infrastructure, service provision, finances, water quality, and governance impact the ability to maintain a given level of access into the future. (Milman and Short, 2008, p.766)

Second, sustainability can be understood as a *desirable direction of development*. Here, good performance equals "moving in the right direction." This approach is progress-oriented rather than target-oriented. For example, instead of achieving a certain amount of gallons per person per day the goal is to continuously reduce water consumption. Sustainability is an infinite endeavor. Performance is evaluated in terms of change over time and each city is its own point of reference. This understanding is evident in the works of Lundin et al. (1999) and the Western Resource Advocates (2010):

A conclusion that can be drawn for the Göteborg water and wastewater system is that the system is moving towards a more sustainable status. Water consumption is decreasing, less drinking water is lost and the quality of the raw water has improved. The efficiency of wastewater treatment has increased as indicated by increasing removal and less resource use, at least for BOD and phosphorus. Recycling of nutrients is however limited and remains a major hurdle for this urban area. (Lundin et al., 1999, p.242)

Because of these differences, the percentage reduction in water use between 2003 and 2008 is used as a data point, rather than the absolute value of system-wide GPCD [gallons per capita per day]. [...] Due to the heavy reliance of many of Arizona's towns and cities on potable groundwater, tracking the reduction in this metric is a good measure of how communities are becoming more water-efficient over time. (Western Resource Advocates, 2010, p.5).

Third, sustainability is understood as a *comparative attribute* meaning more or less sustainable in comparison to peers. Instead of using a city's past performance as point of reference, this approach compares performance across cities. This is done by means of performance scores.

Cities are assigned performance scores, which summarize their achievements in relation to a set of criteria. They are then compared and ranked based on these scores. Cities are evaluated in terms of their position in the overall rank order. The position indicates performance of a city in a given point in time and change in rank indicates relative improvement or worsening in performance. Here, sustainability takes the form of a competition. A prominent example using this approach is the Sustainable Cities Water Index:

European cities dominate the overall rankings, taking seven of the top ten places. [...] No U.S. city makes it into the Index's overall top ten, with the East Coast hubs of Washington DC (13th) and New York (14th) performing significantly better than their West Coast counterparts. [...] It is a rather mixed picture for Asian cities when it comes to water sustainability. Four emerging economy cities—Jakarta (47th), Manila (48th), Mumbai (49th) and New Delhi (50th) finish out the overall ranking, others in Asia fair better. [...] (Arcadis, 2016, p.7)

Finally, we can also understand *sustainability as a choice* and progress as “the right choice.” Making progress towards sustainability means to choose among the possible alternatives the one that yields the best sustainability outcome, given the limitation of the choice. This definition is mostly found in frameworks focusing on evaluation of intervention options. These frameworks provide scenarios for different action plans. They tend to be problem-specific and do not aim for an overall assessment of a city. An example is the approach suggested by Sundberg et al. (2004):

We have a planning and decision process in mind as the context within which the approach can be used. In such situation support tools for comprehensive comparisons between the different available alternatives are crucial and more important than estimations of exactly how sustainable each alternative is. (Sundberg et al., 2004, p.124)

3.4. Data: What data does the framework use?

The data used mainly stems from two sources. These are existing data sources and stakeholder input. *Existing data* include any data that was not originally produced for the purpose of the specific indicator framework. They encompass, for example, annual reports, plans, pre-existing indices, and data collected by organizations as part of their day-to-day business. Existing data may or may not be publicly available and they often need some processing in order to fulfill the requirements of the framework. An example of existing data stems from Xu et al. (2019):

To calculate the basic indices of WRS [water resources sustainability], data of water use, regional water resources, economic product, and population were collected from different sources. Water resources and water usage (domestic water, agricultural water, and industrial water) for each unit were extracted from the China Water Resources Bulletin (Ministry of Water Resources of the People's Republic of China, 2010). Regional economic output value (industry and agriculture) and population data for each unit were extracted from the China Statistical Yearbook (National Bureau of Statistics of the People's Republic of China, 2010). (Xu et al., 2019, p.312)

Stakeholder input refers to data provided by stakeholders such as utility managers, experts, water users, citizens, and government representatives. In contrast to existing data, data gathered through stakeholder input is collected specifically for the purpose of the framework. The data are collected using different methods including questionnaires, interviews, and focus groups. An example of stakeholder input stems from Chesterfield et al. (2016):

The data for AUS [Australia] were collected through a participatory workshop involving a range of participants from key stakeholder

organizations, including local municipalities, the water utility, government departments, and others. The data for SEA [Southeast Asia] were collected through in-depth free-flowing interviews with stakeholders from the local municipality, the water utility and government departments, as well as a desktop review of key policy documents, organizational materials and diagnostic reports. (Chesterfield et al., 2016, p.5)

The selection of data is not a binary choice. Many frameworks combine different types of data from different sources. The OECD Water Governance Indicator Framework (OECD, 2018, p.65), for example, combines “objective information and stakeholders’/expert’s perceptions: the former documents the existence of policy, legal, and institutional frameworks and tools; the latter captures the level of implementation through subjective judgements.”

Data acquisition and data quality are a reoccurring challenge in our material. Authors report problems related to availability, accessibility, acquisition, reliability, quality, and understandability of data, missing data, ease of collection, use of different databases, as well as standardization, consistency, and comparability of data between places and over time. Existing data and stakeholder input tend to differ in these challenges. Frameworks relying on existing data require data to exist, be accessible, and be of good quality. Challenges related to data availability, accessibility, and reliability tend to be more common with this source. Frameworks based on stakeholder input require that stakeholders are available, willing to cooperate, and able to provide the needed information. Challenges related to data collection and reliability of information are more often associated with this source.

3.5. Outcomes: How does the framework summarize the assessment?

The final dimension relates to the information provided to the users of the framework. This information can take many forms such as overall achievement scores, areas of success, areas demanding attention, spider diagrams, and stories of failure or success. Users employ this information to achieve their purpose—e.g., formulating policies or making investment decisions. The kind of information is tied to action potential. For example, an overall achievement score of “good” is likely to initiate different actions compared to listings of areas of “good” and “bad” performance. Based on our corpus, we can differentiate three categories of information.

Overall scores represent the water sustainability of a city in one number. Kramer et al. (2017, p.33), for example, assess utilities using scoring categories. The four categories—80–98, 70–79, 60–69, and below 60—are comparable with educational grading systems thus allowing for a quick overview (ibid). Overall scores are usually derived by aggregating scores relating to different aspects of water sustainability. The scores reported by Kramer et al. (2017), for example, represent the sum of points achieved in terms of 10 evaluation criteria. Overall scores are a prominent choice in our corpus. They allow users to gain a quick overview and to compare cities easily. The drawback of these scores, however, is relatively low information detail. Single scores do not allow users to identify challenges or opportunities. Since they are dependent on the weighting of the included criteria, straightforward interpretation may be misleading. For these reasons, overall scores should be interpreted with caution.

Composite indices provide more information by detailing performance in different areas of water sustainability. The city receives a separate performance score for each of the areas. Sydney Water's (1022, p.44–45) scorecard, for example, tracks performance along the seven goals customer service, water efficiency, water quality compliance, license compliance, ecoefficiency, workforce safety and capability, and business efficiency. Each goal is measured in terms of three to five indicators and the scorecard reports progress for each goal using a 3-point ordinal scale (i.e., “expectations met or exceeded”, “areas to improve”, and “action required”).

Composite indices allow users to gain a more nuanced understanding of strengths and weaknesses. Main challenges associated with composite indices lie in finding a limited set of areas that are generic enough to apply to all contexts, yet specific enough to capture all relevant aspects, or as the [Government of Canada \(2007, p.6\)](#) puts it:

Ideally, all of the indicators will be generic enough to be measurable in all communities yet specific enough to be meaningful. As an example, indicators relating to specific uses of water, such as irrigation and beach closures, should be avoided as they may not be meaningful to most communities. The challenge, then, is to incorporate the concerns associated with such uses as consumption and safety into other indicators that are more widely applicable.

Case studies provide detailed descriptions of water challenges, initiatives, and outcomes of a particular city. Case studies are often used in combination with other types of information. In particular, they are a prominent choice to exemplify the meaning of scores by showcasing excellence or explaining lack of performance. An illustrative example of a case study is the assessment by [Kay \(2000\)](#). [Kay \(2000\)](#) assesses the reliability, resilience, and vulnerability of Israel's water system by looking at the state's hydrology, management, and social susceptibility. His findings indicate that the water system is not operated in a sustainably manner and he delineates several context-specific problems including an overly optimistic stance on the future availability of water, increasing use for agricultural purposes, and climate-insensitive management, allocation, and use of water.

Finally, some documents in our corpus report *city typologies*. These typologies identify clusters of cities which are similar in terms of their water sustainability characteristics. City typologies are by far the least common type of information provided and they are usually tied to scientific purposes. An example is the typology presented by [Van Ginkel et al. \(2018\)](#). The authors differentiate water-abundant and wealthy cities, water abundant and wealthy but (sub)tropical and dependent cities, wealthy and desertlike cities, megacities in emerging economies, and developing cities. These types differ in the level of water security and vulnerability.

4. Discussion: trends in our corpus and their implications

Looking at the options and their combination in our material (see [Table 1](#) for an overview), we find certain systematic patterns of practices or preferences that span multiple design decisions. An illustrative example is the preference for performance overviews over evaluations of interventions. These trends have implications for the usage and benefit of frameworks. Performance overviews, for example, allow cities to identify areas that demand attention. However, they provide limited insights about "what ought to be done." This section delineates five trends that emerge in these data, and discusses their implications.

4.1. Frameworks are predominantly based on thematic structuring

Most frameworks in our corpus emphasize thematic differentiation of factors. The City Blueprint, for example, differentiates eight thematic areas, namely water security, water quality, drinking water, sanitation, infrastructure, climate robustness, biodiversity and attractiveness, and governance. The thematic areas covered are partially overlapping across frameworks thus indicating some agreement.

Thematic elaboration stands in contrast to conceptual distinction. Analytical concepts differentiate "type" of information such as information relating to actions taken, goals achieved, or context that facilitates actions. The distinction of goals, actions, and context allows us to understand if a city is achieving its goals and how its success or failure is linked to presence or absence of action and to favorable or unfavorable context. Such distinction of analytical concepts tends to be less elaborated in our corpus. The tripartite framework of goals, actions, and context is the analytical distinction that we found most meaningful

based on our analysis. However, other categorizations are possible.

An underdeveloped distinction of analytical concepts can impact the value of an assessment. One prominent example of this is the aggregation of factors. Many frameworks in our corpus combine goals, actions, and contexts into a single index. An illustrative example is the resilience score, which combines considerations of contextual challenges (e.g., water stress and flood risk) and actions taken to address these (e.g., size of reservoir). This assumes functional equivalence of these concepts meaning that goals, actions, and contextual factors can compensate for one another. A city with an unfavorable context (e.g., high water stress) can score as high as a city located in a favorable context (e.g., low water stress), given it takes sufficient action (e.g., large reservoirs).

This aggregation of factors may be intuitively plausible but the key question is: how do we know how much action is needed to compensate for an unfavorable context? Due to our limited understanding of complex systems such as water sustainability, these "exchange rates" between concepts are hypothetical or speculative in the vast majority of cases. As a consequence, such aggregation can lead to misrepresentation of performance or challenges.

4.2. Summative evaluation strategies are dominant

There are different ways to characterize the action potential of frameworks. Drawing from the evaluation literature, we can broadly differentiate between summative and formative approaches ([Weiss, 1972](#)). Summative approaches focus on the 'big picture' and describe how well a city performs 'overall.' They are oriented towards the effectiveness of interventions rather than their development and design ([Weiss, 1972, p.17](#)). In contrast, formative approaches focus on producing information "that is fed back during the development of [a program]" ([Weiss, 1972, p.17](#)). They focus on improving interventions and strategies as they are implemented ([Weiss, 1972, p.17](#)).

Summative and formative approaches are fundamentally different in the input they provide to stakeholders. Summative approaches allow stakeholders to gain an overview of a city's performance and challenges. They answer the question: how well are we doing? Formative approaches identify problems and opportunities in the strategies that cities take. They answer the question: what can we do better?

Applying the categories to our corpus, we find a trend towards summative approaches. Most frameworks focus on identifying challenges or assessing predefined goals. Formative approaches are under-represented. Summative approaches are useful for taking an inventory, creating a road map, and monitoring progress. They are, however, limited in helping cities to craft scientifically informed and flexible solutions. Many cities are aware of water related problems but struggle to improve their interventions, maximize the use of limited resources, and deal with conflicting interests. Formative approaches offer an opportunity for the indicator literature to play a more active role in crafting effective sustainability strategies.

4.3. Considerations of capacity are becoming prominent

A city's success in becoming sustainable depends on its ability to formulate and implement targeted and workable policies. Policymaking evolves around internal capacity, governance, negotiation, and collaboration ([Pivo et al., 2020](#)). Capacity is also key for effectiveness of assessment efforts ([Borgnäs, 2016](#)). Studies show that incorrect implementation of assessments and inability to follow through on findings are major reasons for limited impact of assessments ([Eales and Sheate, 2011](#)).

The capacity of the system to take action manifests in different ways in the frameworks. Certain frameworks such as the Water Sensitive Cities Index aim to build capacity as part of the assessment process. They establish dialogue among stakeholders and foster boundary-spanning collaboration (see also [Henry and Vollan 2014](#) for a discussion of the role of networks). Studies on effectiveness of indicators show that

legitimacy and credibility of indicators, often enhanced through inclusion or consultation of stakeholders, enhances the likelihood of implementation of findings (Gahin et al., 2003, p.663; Bauler, 2012).

Other frameworks such as the OECD Water Governance Indicator Framework are designed to evaluate governance capacity. These frameworks focus on identifying governance-related vulnerability that may inhibit a city from formulating and implementing solutions. Yet other frameworks define the boundary of the system under assessment such that governance and capacity aspects fall outside. These are regarded as taking part after the assessment is completed and are not part of the assessment. Put differently, the assessment focuses on evaluating (mostly environmental) challenges but does not take into account the organizational and governance capacity of a city to take action. While not every framework can (and should) account for everything, it is important to be aware that frameworks which do not include capacity related considerations risk to provide mismatched or infeasible policy recommendations.

4.4. Factors are conceptualized as separate entities

Water sustainability is a highly complex task in parts because of the interlinkages between different factors. Goals and actions, for example, may be mutually reinforcing, conflicting, or competing. Actions may foster some goals and impede others. Interlinkages are difficult to operationalize.

This is the likely reason why the majority of frameworks in our corpus conceptualize factors as separate or loosely related entities. They focus on how well a city performs on each of the factors or in each of the management areas. Statements about interlinkages are underrepresented and usually take the form of theoretically-grounded assumptions; these assumptions are rarely stated as testable hypotheses.

While the simplification is understandable, it can limit the usage for policy formulation (Weible and Sabatier, 2017). A good understanding of interlinkages is important for diagnosing challenges and crafting interventions. An example may illustrate this point. Interventions are based on assumptions about cause and effects (Weiss, 1972, p.38). For example, a city may provide financial support to citizens to update fixtures in an attempt to reduce per capita water consumption. This initiative assumes that (a) financial support motivates citizens to take action and (b) updated fixtures lead to a decrease in water use. Any of these assumptions may not hold. Citizens may not update fixtures despite financial support—e.g., because the administrative process is overly complicated or the support only covers a fraction of the cost. Similarly, installation of fixtures may not significantly reduce water consumption—e.g., because water saving fixtures motivate water wasting behaviors or because most demand stems from outdoor use. While this is a simplistic example, it illustrates the benefits of understanding interlinkages for formulating action plans.

4.5. Accounting for context remains a key challenge

Sustainable water management is embedded in a specific city context. This context encompasses characteristics such as geography, hydrology, climate, political economy, and social problems (see also Dietz and Henry, 2008). Context is difficult to include in indicator frameworks because of the tradeoff between universal applicability and relevance (Verma & Raghubanshi, 2018).

The indicator frameworks in our corpus address this challenge in three ways. First, frameworks measure context as a set of predefined variables. These variables are applied to all cities under study and include, for example, urbanization rate, water scarcity, water quality, unemployment rate, poverty rate, and inflation rate (Koop and van Leeuwen, 2015, p.5662). Context is measured as part of the assessment. This approach assumes that the designers know which contextual characteristics are relevant and that these are relatively constant across space and time.

Second, indicator frameworks provide contextualizing information on cities. This usually takes the form of case studies. Case studies discuss in detail the problems prevalent in a city, the interventions taken, and their outcomes. This allows readers to connect the challenges and opportunities evident in the numbers to on-the-ground situations and initiatives.

Third, frameworks include context by allowing city stakeholders to define goals or indicators that they consider relevant. In one framework, regional stakeholders provide the “policy and technical framing of sustainability vision, goals, and objectives” which are then used to choose indicators (Shilling et al., 2014, p.6). This ensures that the water sustainability concerns of the community are reflected in the framework.

These strategies differ in their benefits and drawbacks. Predefined variables allow stakeholders to systematically compare cities. But the selection of these variables likely reflects the interests, values, and concerns of the scholar and they may therefore not be suited to characterize contexts significantly different from the context of framework production. In contrast, factors defined by stakeholders are able to account for issues that are salient and of concern to stakeholder when the assessment is conducted. However, they do limit comparisons and may foreclose less salient but scientifically pertinent issues or issues distant in time. Accounting for contextual factors therefore remains a key challenge in water sustainability assessment.

5. Conclusion

Urban sustainability indicator frameworks are very diverse, with tools designed for different practical use cases and employing different assessment approaches. This heterogeneity makes it difficult, particularly to readers who are new to the field, to overview framework options, identify similarities and differences, and assess transferability.

In this paper, we presented an accessible, non-technical overview of framework designs and current design trends. Based on a systematic analysis of indicator frameworks for urban water sustainability, we identified five key design decisions related to goals, sustainability factors, performance, data, and outcomes. Each decision is linked to a set of common options. In terms of goals, for example, frameworks can aim to benchmark cities, inform policy action, promote learning, and initiate collaboration. While the decisions were identified based on material for assessing urban water sustainability, the categories of decisions and options are relevant to urban environmental sustainability more broadly.

Based on selection and combinations of options in our material, we discuss six current trends in assessment design and their implication for usage and benefit of frameworks. Combined, these trends indicate several limitations (and hence opportunities for future contributions) of current approaches related to: (a) catering action-oriented needs, particularly identification and refinement of context-sensitive, workable solution strategies; (b) clear distinction of analytically different sustainability factors; and (c) ability to account for the complex interdependencies and constraints inherent to environmental management.

Given the increasing popularity of sustainability assessments and the heterogeneity of tools available, we believe that the typology presented here will help scholars and practitioners successfully orienteer the diverse, complex landscape of sustainability indicators. The paper provides framework users a summary of different framework designs and their benefits and drawbacks. This “map and compass” can support the discovery of indicator tools that aligns with local needs and strategies to meet common challenges. Overall, we hope that this introduction to current indicator frameworks and trends gives readers an easy access to the literature and motivates future efforts to systematically evaluate approaches and design meaningful and impactful tools to support a sustainability transition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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