# Chapter 1
# Sustainable Urban Systems: A Review of How Sustainability Indicators Inform Decisions

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**Abstract** The Brundtland commission defined sustainable development as: *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Butlin (1989) Our common future, by World Commission on Environment and Development. Oxford University Press, London, 1987). Translating this definition into an urban context has led to a focus on the use of indicators and indicator sets to quantify sustainability and guide government and stakeholder decisions. Although sustainability assessment methodologies demonstrate a direct link between indicator use and decisions made, there is limited discussion on how indicators actually help decisions. In this review, we examine 22 applied urban sustainability studies to assess whether indicators foster decisions. The 22 studies were analyzed on six dimensions that play a role in indicator development and use: the indicators themselves, stakeholder involvement, geographic and cultural impact, framing sustainability, definition of urban, and decision-making. Our results show that the connection between indicators and their effect on decision outcomes is not considered in indicator development, and although decision-making is briefly discussed by most of the evaluators it is rarely explored in-depth. In addition, vague definitions of sustainability and urban, geographic and cultural diversity, and a lack of concrete measures of the social qualities of sustainability have hampered the ability of indicators to create holistic decisions. We conclude that indicators themselves do not foster decisions and must be applied within a broader framework that can incorporate social and perceptual

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issues with indicators, such as multi-criteria decision analysis. Otherwise, the lack of clarity found in sustainability assessment prevents substantive decisions to improve environmental, economic, and social qualities of urban systems.

## 1.1 Introduction

Urban systems (i.e. cities) are interested in reducing their environmental footprint through methods of sustainable development. Defined by the Brundtland commission as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* [4], sustainable development is a desirable way to improve the sustainability of any urban system. However, urban systems pose challenges when harnessing sustainable development, such as a complex combination of needs and the integration of multiple stakeholder views. The lack of a clear approach is hampered by the inherent ambiguity associated with the Brundtland commission definition. Even in a single city, business, political, social, and environmental interests often reach different conclusions on the best way to meet the needs of current and future generations. Although the ambiguity serves a purpose – no precise definition of sustainable development could incorporate the significant cultural, geographic, and political variations between any two urban systems – efforts to produce sustainable urban systems are still unsuccessful over 25 years after the definition's release.

To assess urban sustainable development, urban sustainability indicators are used. Indicators are quantitative descriptions of the environmental, social, economic, political, and physical qualities of an urban system. Currently, there is no consensus on which indicators accurately address urban sustainability, resulting in a glut of indicators and selection methods [36]. In general, two types of indicators exist for urban sustainability, descriptive and diagnostic [14]. Where descriptive indicators only require direct measurement of an objective, diagnostic indicators try and establish the root causes to unsustainable practices. Diagnostic indicators can provide a more effective tool for solving problems, yet identifying the root-cause of unsustainable social practices is difficult. Descriptive and diagnostic indicators can be further segregated into two categories depending on their application, universal and case-specific. Universal indicators are developed to measure the sustainability of any urban system, where case-specific indicators are created for a single urban system. As the efficacies of descriptive and diagnostic indicators differ, so do opinions on their applications. Some authors argue the development and usage of indicators in a universal context is valuable because it simplifies the promotion of sustainable development world-wide [33, 40]. Others argue that universal indicator applications cannot capture the diverse economic, social, and environmental issues that correspond to urban sustainability [31].This discord attests to the confusion of measuring sustainability.

Since measuring the sustainability of an urban system is too difficult for any single indicator, different indicators are combined into sets. The most common

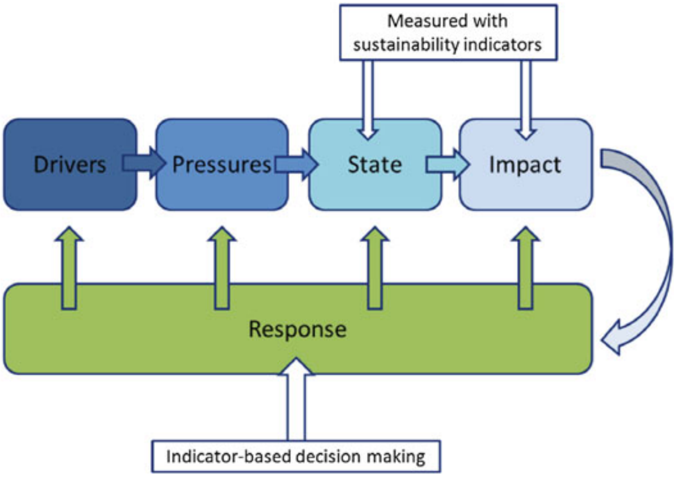


**Fig. 1.1** Driver State Pressure Impact Response (*DSPIR*) model depicting the feed-back loop between changes in the state and impact of a system measured as sustainability indicators and the responsive decisions informed by those indicators

method used to organize indicator sets is to employ the concept of triple bottom line (TBL). TBL is defined as the three pillars of sustainability: the environment, society, and economy. To treat sustainability as the TBL is to consider each pillar equally, where a sustainable urban system must not compromise the quality of one pillar for another, e.g., economic decisions must not cause significant deleterious effects on the environment. Although TBL is used in the majority of urban sustainability applications, the TBL definition of sustainability is not specific enough to guide the creation of sensible indicator sets. Indicator sets found in literature which use TBL for organization are often created with ad-hoc approaches to represent each sustainability pillar, resulting in dissimilar sets. As a result, urban system sustainability cannot be compared directly across studies. Furthermore, the social pillar of an urban system is often poorly represented within indicator sets in comparison to economic and environmental [3].

In urban systems, governments and decision makers utilize sustainability assessments to employ indicator sets for decisions. We explore the importance of indicators for decisions through one of the most prominent assessment methodologies, driver-state-pressure-impact-response (DSPIR) (Fig. 1.1). In the DSPIR framework, the connections between the drivers, state, pressures, impacts, and responses of sustainability in an urban system are represented via arrows. There is a flow of information amongst the driver, pressure, state, and impact nodes that eventually leads to a response (decision). In DSPIR, impacts are defined and measured by indicators, and are the only inputs for response. The reliance on indicators implies that sustainability evaluation plays a key, if not the only, role in how sustainable development decisions are made.

In this chapter, we discuss the use of indicators to guide sustainable development decisions. The current glut of indicators, difficulties in their development, and debate over their use suggests that applications of the DSPIR and similar sustainability assessment methodologies may not be effective. Amongst the myriad of issues surrounding the indicators themselves, there is minimal discussion on whether these indicators foster sustainable development decisions. We address urban sustainability indicators and decisions through an illustrative literature review of sustainability assessments of cities from different world regions. The purpose of this review is to answer three questions:

1. Do urban sustainability indicators foster decisions?
2. Are there missing dimensions of urban sustainability that indicators are not addressing?
3. What tools offer a solution to help indicators foster future decisions?

Question 1 is the primary purpose to conduct this review. Since DSPIR is an iterative process, reflecting on how indicators are being used in real-world applications can improve sustainable development decisions and indicators together. Question 2 is devised to determine if and why some indicator sets foster decisions more readily than others. The failure of TBL to generate holistic indicator sets suggests that current applications must be analyzed for possible "missing dimensions" of urban sustainability. Question 3 attempts to extract answers from successful sustainability assessments. Where no solution was clear, we searched in other fields, namely operations engineering, to find suitable methods.

## 1.2 Literature Review

### *1.2.1 Methods*

Although decisions to include studies in this review were made subjectively, we used specific and consistent selection criteria. Because our focus is on the relationship between sustainability indicators and decisions, particular emphasis was put on applied works that mentioned policy response or decisions. In addition, we sought representation of urban systems that have geographic, cultural, and regional diversity. Peer-reviewed sustainability assessments were accessed through the ISI web of knowledge [37] using the following search terms: indicator*, sustain*, urban or city (882 records); indicator* or metric*, sustain*, urban or city, and decision* (216 records). From these records, 22 applied research articles met our selection criteria.

All 22 articles chosen for this work assessed the sustainability of entire urban systems. The majority of peer-reviewed work collected using our established search terms assessed only part of an urban system (e.g. buildings, or transportation infrastructure). We did not include works of this nature to focus on the sustainability of the entire urban system. This enabled us to make a more focused review on indicators and decision-making with respect to an entire city.

The articles were assessed using six dimensions which were chosen from literature reviews on urban sustainability. These dimensions were: Indicators, stakeholder involvement, geographical location, definition of sustainability, definition of urban, and decision-making. In addition to the six dimensions, missing dimensions emerged during the course of the review and are addressed in the discussion section.

#### 1.2.1.1 Indicators

Indicator and indicator sets were compared on several criteria, including: number of indicators, types of indicators used, and their universal or case-specific application. The dimensions of stakeholder involvement, definition of sustainability, and definition of urban also played an important role in these comparisons.

#### 1.2.1.2 Stakeholder Involvement

The extent of stakeholder involvement in the development and use of indicators was compared in this review. Participation and consensus building are found to be primary components of successful sustainable development initiatives [14]. However in a 2001 survey of 350 U.S. cities, Edward Jepson [19] found that the impediment to action for sustainability was potentially the result of "low public interest, inappropriateness, and lack of knowledge." Comparing the ways stakeholders were involved between studies may correlate to the success of indicators fostering decisions.

#### 1.2.1.3 Geographic and Cultural Impact

We compared how geographic location and culture influenced indicators and decisions in sustainability assessments. The role of geography and culture in sustainability is discussed in recent literature, but questions still arise about their role in global sustainability [3] Regional differences are apparent in sustainability measurements, but the public's perception of what makes a city livable and functional play a large factor in whether a city is sustainable and this is not accounted for in most assessments. For example, what someone in Shanghai considers sustainable can be dramatically different from a person in San Francisco – cultural viewpoints can skew opinions such that environmental quality may only play a small role in overall sustainability.

#### 1.2.1.4 Framing Sustainability

How the term sustainability was used in the articles was noted in order to see the overlap or ambiguity in how research is framing the basic idea of sustainability. Indicator selection is driven by how sustainability is defined. Because there is no universally accepted definition of sustainability, the concept of sustainability varies from city to city and results in diverse goals and indicators [16]. In other words, the questions and goals of an assessment influence their conclusions.

#### 1.2.1.5 Defining Urban

Studies included in this review were compared based on population size, location and geography of the cities they assessed. Defining what makes a city habitable, livable and sustainable drives indicator development as much as the definition of sustainability. Within the United States the definition of a city varies from state to state [32]. Similarly, European cities are labeled differently depending on location. While urban areas and cities are often used interchangeably, an urban area is defined by governments as a having a significant population density and built-up growth [39]. Thus, a populated "city" and a densely populated urban area may be characterized as the same entity, making comparisons between some indicators and decisions inappropriate.

#### 1.2.1.6 Decision-Making

The purpose of this review is to assess how indicators foster decisions. We broke this analysis into two parts. We first noted which sustainability assessment methodology (if any) was used in each study to connect indicator sets and decisions together. Second, we analyzed the text of each study to compare how decision-making is discussed with respect to indicator use.

## 1.3 Results

Table 1.1 summarizes the 22 studies included in this review. Even with the vast diversity between studies, there are common elements between indicator sets and sustainability assessment methods. Many indicator sets include similar indicators if they were from the same region. For example, disposable income per household, life expectancy, population size were common indicators used in Chinese sustainability studies, and instead, quality of life indicators such as resident satisfaction and community participation were used in European and American studies [45]. In many cases, specific indicators had the same measurement goal (i.e. air quality),

**Table 1.1** Summary of studies included in this review

| Study # and reference | Area of study | Population size | World region | Amount of indicators | Indicator type | Indicator application |
|---|---|---|---|---|---|---|
| [1] Gonzalez-Mejia et al. [11] | City of Cincinnati, suburbs and metropolitan statistical area | 2.1 million | North America | 60 | Descriptive | Case specific |
| [2] Huang et al. (1997) | Taipei, Taiwan | 2.7 million (at time of study) | Asia | 80 | Diagnostic | Case specific |
| [3] Lee and Huang [23] | Taipei, Taiwan | 2.6 million | Asia | 51 | Diagnostic | Case specific |
| [4] Fan and Qi [8] | 31 Chinese Cities | 1.4–32 million | Asia | 5 | Diagnostic | Universal |
| [5] Yuan et al. [45] | Chongming County, Shanghai | 0.7 million | Asia | 17 | Diagnostic | Case specific |
| [6] Moussiopoulos et al. [29] | Thessaloniki, Greece (GSA) | 1 million | Europe | 88 | Diagnostic | Case specific |
| [7] Huang et al. [17] | Taiwan | 23 million | Asia | 22 | Diagnostic | Case specific |
| [8] Jarrar and Al-Zoabi [18] | Jerusalem | 801,000 | Middle East | 6 | Diagnostic | Case specific |
| [9] Li et al. [24] | Jining city | 7.9 million | Asia | 52 | Diagnostic | Case specific |
| [10] Scipioni et al. [33] | Padua, Italy | 210,000 | Europe | 70 | Diagnostic | Case specific |
| [11] Duran-Encalada and Paucar-Caceres [6] | Puerto Aura, Mexico | Unavailable | North America | 34 | Diagnostic | Case specific |
| [12] Van Assche et al. [40] | 13 Flemish Cities | ∼60,000–600,000 | Europe | 200 | Diagnostic | Case specific |
| [13] Posner and Costanza [29] | Baltimore | 5.8 million | North America | 25 | Descriptive | Universal |
| [14] Kohsaka [22] | Nagoya, Japan | 2.2 million | Asia | Does not report indicators used | Unavailable | Unavailable |
| [15] Yu et al. [43] | Yantai, China | 6.5 million | Asia | 36 | Descriptive | Case specific |
| [16] Chunmiao and Jincheng [5] | Harbin city, China | 9.47 million | Asia | 37 | Diagnostic | Case specific |
| [17] Budd et al. [3] | 49 US urban areas | 150,000–2.1 million | North America | 5 | Diagnostic | Universal |
| [18] Yu and Wen [44] | 46 Chinese cities | 500,000–23 million | Asia | 10 | Descriptive | Case specific |
| [19] Wen et al. [42] | 6 Chinese cities | 1–10 million | Asia | 1 | Descriptive | Universal |
| [20] Van Dijk and Mingshun [41] | 4 Chinese cities | 340,000–2.6 million | Asia | 22 | Descriptive | Universal |
| [21] Abusada and Thawaba [1] | Ramallah Governorate, Palestine | 279,730 | Middle East | 20 | Diagnostic | Case specific |
| [22] Gagliardi et al. [10] | Naples, Italy | ∼3 million | Europe | 18 | Diagnostic | Universal |

(continued)

**Table 1.1** (continued)

| Study # | What stakeholders were involved? | Who chose the indicators used? | How does the study frame sustainability? | Definition of urban | Decision-making addressed? |
|---|---|---|---|---|---|
| [1] | None | Authors | TBL | None | No |
| [2] | NGOs and public | Authors | TBL | Heterotrophic system | No |
| [3] | Experts and government | Authors | TBL with institutional, political | None | No |
| [4] | None | Authors | TBL | None | No |
| [5] | Government and academic | Authors | TBL | None | No |
| [6] | Public | Authors | TBL | Defined by TBL | No |
| [7] | Experts | Stakeholders | TBL with physical | Defined by TBL | No |
| [8] | Experts | Authors | TBL | Defined by TBL | Address decision-making without stakeholder engagement |
| [9] | None | Authors | TBL with cultural | Complex ecosystem | No |
| [10] | Public | Stakeholders | TBL | None | No |
| [11] | Project Manager and Gov't | Stakeholders | TBL with institutional | None | No |
| [12] | Government | Stakeholders | TBL with institutional, physical, activities | None | Address decision-making but framework use not discussed |
| [13] | None | Authors | TBL | None | No |
| [14] | Undefined | Stakeholders | TBL with political | None | Address decision-making without inclusion of indicators |
| [15] | None | Authors | TBL | None | No |
| [16] | None | Authors | Economy, society, population, resources | Artificial/complex ecosystem | No |
| [17] | None | Authors | TBL with political | None | No |
| [18] | None | Authors | TBL | Combination of three complex systems | No |
| [19] | None | Authors | TBL with political | Combination of five complex systems | No |
| [20] | Experts | Authors | Urban Status, coordination, and potential | None | No |
| [21] | Experts and public | Stakeholders | Government, physical, socioeconomic, infrastructure availability, environment | None | No |
| [22] | None | Authors | Economy, environment, energy and urban plan | None | No |

*TBL* triple bottom line

but approached it differently. For example, Fan and Qi [8] used quantitative sustainability data such as air quality, traffic noise, etc. while Wen Yuan et al. [45] incorporated indicators such the level of environmental quality enhancement.

### *1.3.1 Indicators*

The number, type, and application of indicators varied widely throughout the studies (Table 1.1). The largest set of indicators was 200 [40] where some studies used as few as five indicators [8]. Indicators developed with stakeholder input were specific to the region being studied [23, 43].

While some researchers cite the importance for universal indicators, only six studies used universal indicator sets. Scipioni et al. [33] reviewed the use of ISO 14031 in Padua, Italy, which is a universal framework for measuring sustainability. They found that implementing context indicators in a top down approach allowed locals to view their city in time and within the context of global sustainability. Posner and Costanza [31] combined 25 separate indicators into the Genuine Progress Indicator (GPI), to measure the sustainability trends in Baltimore, Maryland. GPI is an alternative approach to GDP which incorporates environmental factors into economic analysis. The authors found that the GPI is easily reproducible and comparable across levels such as cities, counties and states, though the author's state that there is no mutually agreed upon way to use GPI. van Dijk and Mingshun [41] use the Urban Sustainability Index (USI) to measure the urban status, coordination, and potential of four Chinese cities. USI emphasizes sustainable use of natural resources as well as minimizing impacts of pollutants. The studies that utilized universal frameworks provided a global perspective for cities to benchmark their progress.

A global perspective was implemented in the 15 case-specific studies which did not employ universal indicator sets. This was accomplished by reference to studies which used universal indicator sets or UN/OECD reviews when developing their respective sets [6].In addition, the authors employed various frameworks to guide their studies in order to integrate their research into a global context. However, it was acknowledged that issues arose in combining global perspectives and local policy action.

### *1.3.2 Stakeholder Involvement*

The majority of studies suggest that indicators are being derived using stakeholder involvement from multiple sources, including: experts, government, NGOs, or citizens. Specific works discussed how to foster decisions using indicators through stakeholder involvement. Stakeholders should be involved as early in the indicator development process, otherwise, it is difficult to assess the decision-making

**Fig. 1.2** Locations of case studies. The *larger dots* represent case studies which examined more than one urban area in a region. If more than one study was completed in a single urban area one dot is used

possibilities. Moussiopoulos et al. [29] suggest a "fruitful public dialogue" on indicators after stakeholders reach a consensus among themselves. For environmental management projects, decision makers often use four generalized types of project inputs: the results of modeling and monitoring studies, risk assessment, cost-benefit analysis, and stakeholder preferences [21]. Incorporating stakeholder preferences poses the most considerable challenge, as it enables the influence of biases and misunderstanding. Van Assche et al. [40] suggest that using a participatory approach fosters the use of community indicators and generates interesting side effects such as networking within and between city authorities. Van Dijk and Mirgshun [41] point to three elements for successful participation in urban sustainability management, which are: availability of information, stakeholder consensus and public supervision of projects to ensure the fulfillment of goals.

### *1.3.3 Geographic and Cultural Impact*

The 22 case studies are geographically and culturally diverse. Twelve of the studies were located in Asia, six in Europe, and the remaining four were in North America (Fig. 1.2). The urban areas ranged in size from large, dense capital cities [27], to small urban areas [11]. Explanations of what constitutes an urban area vary greatly between studies on two sides of the world. For instance, in the United States, rural areas near urban developments are not included within the "system". In contrast, in China, local rural areas are often included in "urban" studies [17]. Variations also existed in terms of region, climate, population size/density, and political climate. For example, Moussiopoulos et al. [29] assessed Thessoloniki, Greece which has a population of one million, while Abusada and Thawaba [1] assessed the Ramallah governorate in Palestine which only has a population of 200,000. No studies were found to include cities in the southern hemisphere.

### *1.3.4 Defining Sustainability*

Though the TBL and the Brundtland definition were commonly cited, there is ambiguity in how sustainability is defined between papers. Lee and Huang [23] discuss that although the Brundtland definition is widely recognized as the foundation of sustainable development goals, it is too broad and ambiguous because it strives to find a perfect balance which is difficult to attain. In 10 studies, the authors describe sustainable development in terms of TBL, as a balance between environmental, social, and economic pillars. In six studies, the authors describe sustainable development as the same three pillars plus one. The additional pillar varied from institutional [23] to physical [17] aspects of urban systems. Additional pillars also suffered from vague definitions, such that ad hoc approaches were still employed to determine final indicator sets and studies which use the same additional pillar use different indicators.

### *1.3.5 Defining Urban*

Only eight studies gave a definition of what the author's deemed to be a city or urban system. Three of the studies define an urban system as an expansion of TBL (Moussiopoulos et al. [29], Huang et al. [16]; Jarrar and Al-Zoabi [18]). Although this creates consistency within the study, TBL as a vague concept fails to frame an urban system in a consistent manner. Five studies created a unique definition of urban system. Four of these five used the term "complex system" to suggest that an urban system is a combination of both man-made and natural components [5, 24, 42, 44]. Although these four studies use similar terminology, each suggests different system components define an urban system. Overall, the limited, vague, and conflicting definitions of an urban system within studies indicates.

### *1.3.6 Decision-Making*

Instead of using only indicators for assessing sustainability, every study integrated the indicators with methodologies to provide a visualization of context, linkages, and trade-offs. For example, Driver-Pressure-State-Impact-Response, or similar methods, was used in six studies (Fan and Qi [8], Duran-Encalada and Paucar-Caceres [6], Kohsaka [22], Huang et al. [16], Huang et al. [17], Scipioni et al. [33]). Many authors combined DSPIR with other methodologies to provide a more robust sustainability assessment, such as Scipioni et al. [33] which combined DPSR (without impacts) and ISO standard assessment methods.

No study included in this review, or found using our search terms, discussed the substantive policy or decision outcomes by using assessments or indicators. Those that discussed decision-making or policy did so by exploring the importance of trade-offs in stakeholder involvement and policy integration [3, 17, 22, 23, 29, 33, 41]. Certain studies focused on solely benchmarking a city's sustainability, while others focused on the indicator development process in order to open communication among stakeholders and policy-makers. Yu and Wen [44] explained that benchmarking is important for less sustainable cities, while Van Assche et al. [40] believe that sustainability assessments should be used as decision aides rather than benchmarks. Multiple studies discussed the importance of visualization for decision-making and stakeholder involvement and this was illustrated in different forms. Some studies used visuals such as smiley faces or −/+ to show the state of the indicators [24, 29, 31]. Huang et al. [17] took a less simplified approach and created a sensitivity model in order to enable consensus around possible policy change. Communication, simplicity of indicators, and inclusion of stakeholders were common themes throughout the studies. Authors discussed inter-disciplinary communication, further integration of decision-making and comparisons between the global and local level as important topics for future research [3, 22, 45].

## 1.4 Discussion

### *1.4.1 Do Urban Sustainability Indicators Foster Decisions?*

There were successful examples of indicators fostering sustainability engagement within our review. In general, two types of indicators are used for urban systems: descriptive and diagnostic [14]. In Thessoloniki Greece, Moussiopoulos et al. [29] developed a system of indicators that were understandable for stakeholders in order to create an effective management assessment. By building a consensus among stakeholders from the beginning, the indicators better reflected the true opinions of the local community and as a result are expected to better inform the local decision-making body. The studies that did not act as benchmarking tools, but rather as sources for communication and knowledge sharing, were more effective in incorporating decision possibilities in their outcomes. Scipioni et al. [33] successfully created a set of indicators by encouraging participants to "comment, share or modify political choices" after building consensus around TBL critical issues. Decision-making is limited to available local knowledge, yet indicators will be ineffective if they do not fit in with the local policy debate. In order to influence policy and decision-making, indicators must be able to integrate with policy directions as they did in van Assche et al.'s [40] study of Flemish cities.

Based on the reviewed case studies, we found that sustainability indicators alone were ineffective at promoting decisions. The studies that employed general metrics offered only cursory evaluations or city-to-city comparisons. In the case study of Baltimore, the use of GPI was effective as a benchmarking tool but there was no indication of which indicators were important to the local population, or what changes would be the most effective in treating un-sustainability [31]. Indicator systems developed for a specific urban system had more practical application, yet either ignored key sustainability features or had impractical goals. Fan and Qi [8] used only the following indicators: GDP per capita, air quality, traffic noise, rural/urban income ratio, and urbanization level. Similar to the issues with generalized frameworks, these metrics give little indication of social goals or concerns making it difficult for policy or decision makers to translate into actions. Considering stakeholder opinions was suggested for policy implementation, but it was not always effective. Yuan et al. [45] incorporated public participation from the beginning of their study of Chongming County in Shanghai, and through their consultations discovered that each sector of the community interpreted sustainable development differently. This resulted in regional variations in stakeholder opinions.

### *1.4.2 Are There Missing Dimensions of Urban Sustainability that Indicators are Not Addressing?*

A key component to decisions that is not addressed by indicators is conceptual differences between people and regions. The way that people perceive complex terms such as sustainability and urban systems has a direct effect on the success of the assessments studied in this work. Additionally, the segregation of an urban system into environmental, social, economic, and institutional sections is difficult to realize since each of these sections themselves are systems of systems. No matter how well the indicators represent an urban system, there is bound to be a loss of information that makes decisions harder to manage.

The general perception of urban sustainability assessment and management interfere with decision making. In particular, the translation from indicators into decisions fails due to an inability to compensate for fundamental differences in how sustainability and urban systems are defined by individuals. Although there is a near universal acceptance of TBL as an effective basis for sustainability assessment, the definition is too vague to foster practical application [30]. Beyond the pillars of TBL, there is also the component of time that is never addressed by the indicators or assessment methods. TBL represents a spectrum of viewpoints on sustainability with respect to time, ranging from highly reliable urban systems that do not change to those that are designed for constant replacement and re-engineering. Even though a strong environment, society, and economy are the goal of every assessment, it is almost impossible to assume that any two evaluators or decision makers will have an identical perspective. These inherent differences are why a single urban sustainability assessment method has not been accepted universally [34]. In fact, just the term "sustainability assessment" is difficult to define in a universal context [30]. Yuan et al. [45] explain that because the stakeholders involved in the assessment process define sustainable development differently, differences are reflected in the indicators. This implies that the indicator frameworks have the potential to be either ineffective at conveying useful information, or worse, presenting bias that might lead to undesirable decisions.

Cultural and geographic information also played a key role in shaping how evaluators and decision makers perceived sustainability and urban systems. The dramatic differences between where a city was located and how "urban" was locally defined directly affected the outcome of sustainability assessments. For instance, in assessments of Chinese cities, Li et al. [24] explained that urban areas include traditionally classified rural areas because they fall under the administrative reach of a nearby city. There are three tiers of cities in China as determined by the Chinese Urban Planning Act, so an area with a population as small as 60,000 is still deemed a city. Within this research only one study referenced this Act and included which tier the assessed city was categorized under [8]. The end result of this could be substantially different results city to city, making cross comparison inconsequential.

Where economic and environmental goals might be easily reduced into an indicator, the measurement of the social facets of sustainability is much more difficult. The DSPIR framework used by the studies in this review follow a "reductionist" paradigm that fails to compensate for the complexity of social networks and interactions [14]. Previous studies correlate urban sustainability planning and policies to a region's social and political culture [3]. Within the context of this work, characteristics of a thriving social network such as the creative class [9] and political structure were widely ignored. In the studies that relied heavily on stakeholder involvement, the focus was predominately on the measurable qualities of sustainability and there was little to no discussion on what makes an urban area a desirable place to live. Van Assche et al. [40] discusses quality of life in the article, but the indicators used are typical of the social factor of TBL, e.g. unemployment rate and education. There is a general lack of discussion about what constitutes a thriving urban area, and instead an emphasis on creating indicators for the sake of measurement.

### *1.4.3 What Tools Offer a Solution to Help Indicators Foster Future Decisions?*

In this work, indicators alone were not effective at informing decisions. In general, substantive decisions result from understanding the problem, obtaining stakeholder opinions and engagement, and generating alternatives [12]. The inclusion of stakeholder opinions and generating alteratives creates confusion when using indicators by themselves. Instead, a framework that can combine decision needs with indicators is recommended to improve decisions and allow faster reassessment and changes to urban sustainability plans [26, 28]. Huang et al. [17], created a sensitivity model to visually display the interrelationships among indicators chosen by expert participants. They found that when the experts were able to visualize the interrelationships, it was easier to arrive at a consensus for specific policy recommendations. While sensitivity modeling is an effective way to approach sustainable decision-making, it is a complex process. Brunner and Starkl [2] reviewed decision aid methodology with a focus on multi-criteria decision support, which provides a less technical approach that would be better applied to policy experts. Despite the inability of indicators to promote urban sustainability decisions, decision frameworks can assist in their application. In particular, multi-criteria decision analysis (MCDA) offers specific benefits that can improve urban sustainability decisions, by exposing the linkages between indicators and weighing stakeholder opinions [25].

The Economic Development Administration describes MCDA as an aid for decisions, education, planning and communication of information [38]. For example, MCDA can be used to optimize project impact (design tool), to winnow or compare projects (decision tool) and to describe project impact (communication tool). MCDA has been used in various applications such as adaptive and environmental management [15, 20, 26]. In our review two studies used the analytic hierarchy process (AHP) MCDA method to benchmark sustainability [5, 43]. Although both studies used weighting systems in order to benchmark sustainable development, stakeholder values were not studied or used for weighting criteria. As a result, data transparency is lost, and sustainability assessment was still ineffective at promoting decisions. If indicators are going to foster substantive decisions, applications of MCDA must be more transparent to stakeholders and decision-makers involved. The utility of MCDA in the urban sustainability context is its ability to overcome perceptual, cultural, and social issues that hamper indicator applications. Future indicators and indicator sets must not only consider stakeholder involvement in indicator development, they must also consider decision-maker needs and perceptions at an early stage. Only then can the results from a sustainability assessment elicit a substantive response to unsustainable practices.

Furthermore, the use of MCDA in an assessment framework such as DSPIR offers the possibility to generate more valuable sustainability indicators via iteration. It is difficult to create an initial sustainability assessment that includes a precise definition of sustainability and urban, stakeholder involvement, and geographic and cultural implications on local needs. Initial assessments are bound to overlook key elements of the urban system sustainability simply because it was impossible to recognize their importance pre-assessment. Once indicators are developed and the urban system is assessed, combining this information with decision-maker viewpoints will reveal new assessment needs and help refine current indicators to offer more accurate measurement. The primary purpose of the iterative DSPIR processes in Fig. 1.1 is to measure progress and refine responses with previous indicators. With MCDA, this process can include the addition of new indicators, changes to previous indicators, and even improve sustainability and urban definitions and local understanding of geographic and cultural factors.

## 1.5 Conclusion

Developing sustainable urban systems requires the use of indicators, but it is still unclear how they foster decisions. The 22 studies herein utilized diverse indicators and indicator sets, had varying amounts of stakeholder involvement, and were from different geographic and cultural regions. Definitions of sustainability and urban remain vague amongst studies, resulting in ineffective assessments. Although case-specific applications were more successful at incorporating stakeholders into the assessment process, there was still limited discussion on the use of indicators for decisions. Therefore, even after the inclusion of stakeholder and expert information, few assessments offered actual decision support. The reasons enumerated above demonstrate that the attention used in the creation of indicator sets must also be applied to the decisions they are supposed to support, or substantive decisions are not possible.

We found that the use of indicators tends to ignore major conceptual issues surrounding sustainability assessment. Missing dimensions from current indicators and indicator sets include: vague applications of TBL, constant redefinition of the word urban, ignoring how different people have different viewpoints on sustainability, and reducing complex social qualities of urban systems into a single value. Ignoring each of these issues can lead to biased, ineffectual, or even harmful decisions. None of the studies included in this review could manage these issues due to a narrow focus on indicators.

A possible solution to the issues preventing urban sustainability decisions is the use of MCDA. MCDA can weigh indicators alongside various opinion and conceptual differences. Although two studies included in this review utilized MCDA, they failed to include stakeholder needs, ruining the possible transparency of the studies. Having a transparent connection of indicators to stakeholder and decision maker needs can provide a more legitimate means to foster decisions and improve the environment, society, and economy simultaneously. In addition, MCDA can help create more precise and effective indicators through iteration. It is difficult to successfully include all important urban sustainability dimensions into an initial assessment. With MCDA, assessment iterations not only improve responses, but refine the indicators as well.

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