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Measuring the sustainability of cities: An analysis of the use of local indicators

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ABSTRACT

We analyze 17 studies of the use of urban sustainable development indicators (SDI) in developed western countries. The analysis reveals a lack of consensus not only on the conceptual framework and the approach favored, but also on the selection and optimal number of indicators. First, by performing different classifications and categorizations of SDI we identify problems inherent in territorial practices that use SDI. Second, we argue that the lack of consensus in several steps of the creation of SDI stems notably from the ambiguity in the definitions of sustainable development, objectives for the use of such indicators, the selection method and the accessibility of qualitative and quantitative data. Third, based on the reviewed studies, we propose a selection strategy for SDI through which we demonstrate the need to adopt a parsimonious list of SDI covering the sustainable development components and their constituent categories as broadly as possible while minimizing the number of indicators retained.

1. Introduction

The World Commission on Environment and Development (1987) proposed the most consensual definition of sustainable development to date: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." More specifically, as specified in the Brundtland report (WCED, 1987) the concept of sustainable development comprises three aspects: economic, social and environmental.[1] In addition, for development of a given territory to be considered sustainable, it must integrate the qualities associated with interactions and overlapping of these dimensions. Accordingly, development must be equitable (interaction between the economic and social dimension), livable (correspondence of the environment to social needs, which can refer to the concept of quality of life) and viable (economic development must abide by the supportive capacity of the ecosystems, and depletion of non-renewable resources must be avoided). These dimensions are represented in Fig. 1.

If the concept of sustainable development was initially directed at nations through Agenda 21 resulting from the 1992 Rio Summit, a growing number of experts recognize that it is at the local scale, i.e. at the level of municipalities, cities or metropolitan regions, that the challenges are best expressed and that actors must be mobilized (Camagni, 2002). In this sense, Article 28 of Agenda 21 which recognizes the importance of actions at the local scale, led to the creation of Local Agenda 21 adopted by several thousand municipalities around the world (UNCSD, 2002). Sustainable development indicators (SDI) thus appear to be a means increasingly used by public administrations to underpin their sustainable development strategies, notably by allowing tangible assessment and monitoring systems. Despite their popularity, the use of SDI remains problematic in that the absence of a less general and more universal definition of sustainable development has given rise to multiple interpretations and in particular has triggered an explosion of indicators.

In this paper, we study the use of SDI for cities located in developed western countries. Our analysis demonstrate a lack of consensus in several steps of the creation of SDI that stems notably from the ambiguity in the definitions of sustainable development, objectives for the use of such indicators, the selection method and the accessibility of qualitative and quantitative data. Based on 17 reviewed studies, we propose a selection strategy for SDI through which we demonstrate the need to adopt a parsimonious list of SDI covering the sustainable development components and their constituent categories as broadly as possible, while minimizing the number of indicators retained.

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[1] Recently, a fourth dimension has been added: the institutional dimension of development. To simplify the presentation, we limit the analysis to the three original dimensions of sustainable development. We thus integrate the sub-categories of the institutional component in the social dimension.

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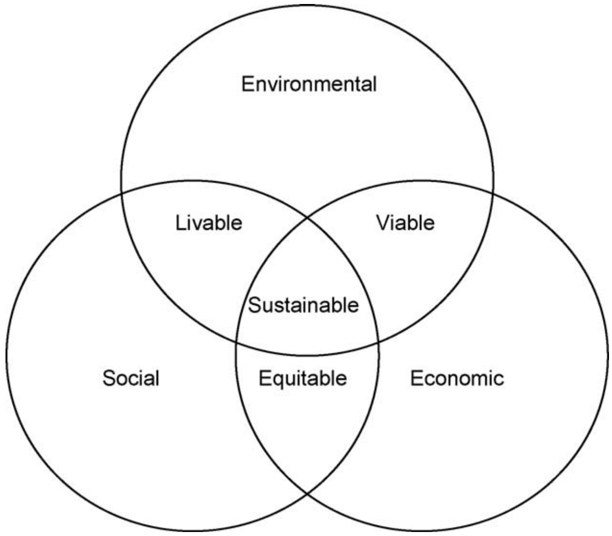


Fig. 1. Classic dimensions of sustainable development.

In Section 2 we describe the indicators and indices of sustainable development, along with the related basic concepts. In Section 3, we present the 17 studies from which we extracted the 188 SDI and interpret the classifications and categorizations of these indicators. In the following section, we perform a more detailed empirical analysis of the SDI compiled and discuss the reasons for the lack of consensus we observe. In Section 5, we develop a strategy for selecting SDI based on a review of previous studies, underlining the need to adopt a parsimonious list of SDI with a broad coverage. The conclusion follows.

2. Indicators and indices: basic concepts

This study investigates indicators of sustainable development in general rather than problems related to their aggregation, weighting, etc. However, for simplification purposes, before beginning the analysis of the studies inventoried, we present some basic concepts related to sustainable development measures (e.g. indicators). First we differentiate indicators from indices. We then briefly discuss important concepts that underlie the construction of indicators and indices: aggregation, weighting, thresholds and target values.

2.1. Indicators vs indices

2.1.1. Indicators

First, it is important to clarify the nuance between indicators and data or variables observed. A datum or variable observed becomes an indicator only once its role in the evaluation of a phenomenon has been established. For example, the number of unemployed is a datum or key variable in economics. Once it is determined that an increase in the number of unemployed expresses negative economic performance for a given territory, this number becomes an indicator. The datum or variable pertaining to the number of unemployed can then be standardized, transformed or formulated in any way (e.g. rate, level) that can account for economic performance.

2.1.2. Indices

An index (or composite indicator) is a synthesis of indicators. Formalization of an indicator that necessitates the aggregation of several data or variables results in an index. The use of indices in the field of sustainable development facilitates the understanding and interpretation of indicators of a given phenomenon, particularly for the public.

To illustrate, we consider the human development index (HDI) created by the UNDP in 1990 that clearly conveys the nuance between an index and an indicator. The HDI consists of three indices (longevity, level of education and standard of living). Each index synthesizes a set of indicators. For example, the level of education index is a synthesis of the indicators “gross literacy rate” and “gross education rate.” The index is then calculated based on an aggregation method.

2.2. Aggregation, weighting, critical values and thresholds

2.2.1. Aggregation

Aggregation can be spatial (e.g. progression from a regional spatial scale to a provincial scale), temporal (e.g. from a monthly interval to an annual interval) and thematic. The first two aggregation modes apply to a given variable that is compared over time or between territories with the same administrative status. In contrast, thematic aggregation groups a set of indicators according to different themes, and is used to produce indices. The aggregation method of indicators selected determines the conceptual framework used. This framework refers to a method or set of organization methods intended to design and structure a vision of sustainable development (e.g. organization into three dimensions of sustainable development: environment, economy and society).

2.2.2. Weighting

Weighting may entail attributing a greater value or contribution to one indicator or index than another. This approach has drawn much criticism (Perret, 2002; Martinez-Alier et al., 1998) because it is an arbitrary process and no weighting structure can rationally justify the attribution of a given weight (e.g greater weight) to a given indicator. Nonetheless, Callon et al. (2001) suggests that any attempt to weight sustainable development indicators take public participation in decision-making processes into account.

2.2.3. Threshold, critical value, target value, relative performance

The concept of threshold refers to a scientifically demonstrated reference value which causes the phenomenon described to change status and present notable discontinuities and structural changes or irreversibilities. It applies mainly to environmental challenges (e.g. water pollution, soil contamination and air pollution).

The critical value corresponds to a recognized, generally arbitrary, reference value derived from standards. It takes into account uncertainties and individual and/or group interests. For example, the figure of 30% of income allotted to housing is often considered a critical value to determine whether a household falls below the poverty level.

The concept of target value allows objectives to be set while measuring efforts and associated costs (economic, social and political).

The relative performance of a given territory refers to the reference values based on other territories of the same stature. These benchmarks are consequently used to construct statistical distances relative to the best and the worst performers. Relative performance is generally used in cases where indicators and indices have no scientifically established thresholds or consensual critical values. Thresholds are then determined based on the experience of other territories.

As mentioned above, in this study we concentrate on the indicators themselves rather than on questions related to their aggregation, weighting etc. The studies retained therefore serve to demonstrate how indicators are chosen based on a broader

Table 1
Summary of the 17 studies.

#	Reference	Regions and cities' populations	Specific features of study	# of indicators
1	Ambiente Italia Research Institute (2003)	42 municipalities, EUR (13 with population over 350k; 18 with population 100k to 350k; 11 with population less than 100k).	System of indicators based on a limited number of themes, resulting from a lengthy analysis on the European scale. Record for each indicator retained.	10
2	Corporate Knights (2007)	24 cities, CAN (population over 100k).	Comparison of cities according to six weighted categories of indicators.	35
3	Federation of Canadian Municipalities (2004)	20 cities and regional municipalities, CAN (population over 100k).	Comparison according to indicators sorted along 11 dimensions. Comparison over time.	72
4	Tomalty (2007)	27 municipalities in Ontario, CAN (nine with population over 400k; nine with population 75k to 400k; nine with population less than 75k).	Comparison of municipalities according to indicators that meet determined objectives, associated with three main dimensions of sustainable development.	33
5	SustainLane Report (2007)	50 cities, US (50 largest cities in US).	Comparison of cities according to 15 weighted categories of indicators.	15
6	Jacksonville Community Council (2004)	City of Jacksonville, US (Metropolitan area population 1.3m)	Selection of indicators based on 15 criteria, meets nine objectives.	86
7	Cowley et al. (2007)	20 cities, UK (population over 300k).	Selection of indicators based on three objectives that reflect the sustainability of a city.	13
8	Koller (2006)	31 cities, SWZ (population over 20k).	Standardized indicators transformed into deciles: cities are assigned a grade of between 1 and 10 by indicators. Results presented according to a dashboard of cities.	30
9	Meier and Wachter (2005)	14 cities and 8 cantons, SW (cantons' population 500k to 1m.; cities' population 10k to 100k).	Use of five criteria in the choice of indicators. Record for each indicator retained.	35
10	Fraser Basin Council (2000)	Fraser Bassin, BC, CAN (region's population of 2.77m).	Choice of indicators based on 8 criteria corresponding to four objectives.	40
11	Sustainable Calgary (2004)	Calgary, Alberta, CAN (metropolitan area population, 1.6m).	Choice of indicators based on eight criteria. Discussion groups were formed to determine the indicators that best correspond to their territory.	36
12	Boston Foundation and Greater Boston's Civil Community (2007)	Boston, US (Metropolitan area population, 4.4m)	Identification of several dimensions whose issues are part of a global vision of sustainable development	28
13	Brazzini-Mourier (2006)	Onex, SWZ (population 20k).	Decision-making tool. Record for each indicator retained.	39
14	Planque and Lazzeri (2006)	34 communes in Communauté du Pays d'Aix, FR (one with population of 135k; four with population over 10k; 29 with pop less than 10k)	Summary of several experiences with territorial indicators, methodology and construction of a benchmark. Detailed record produced for each indicator.	74
15	Agence Régionale pour l'Environnement (2001)	67 cities, Midi-Pyrénées region, FR (population over 5k).	Record for each indicator retained.	27
16	ARCOLATINO.org (2004)	Cities in Arco Latino[9] (population 200k to 400k).	Record for each indicator retained.	21
17	Thomas (2003)	n/a	Compilation of indicators from OECD, Eurostat, United Nations Commission for Sustainable Development, European Structural Indicators. Only 22 indicators out of several hundred are common to these large entities. Analytical and comparative study.	22

[9] Arco Latino is an association of regional and departmental communities corresponding to islands, coastal and inland regions in the Western Mediterranean (Portugal, Spain, France and Italy).

analysis, e.g. based on an index. In the following section we present the studies analyzed.

3. Description of surveyed studies

We initially compiled a sample of 23 studies that apply indicators related to sustainable development to one or more cities or urban centers covering a broad array of western countries, provinces and states. We subsequently decided to limit our analysis to studies specifically covering urban indicators of sustainable development for four main reasons.

First, we believe that cities should be the object of closer scrutiny since the majority of developed economies' population live in cities and that because of that they are exposed or are the source of many SD related problems such as pollution, crime, housing etc.... and this is particularly true in western countries (Thomas, 2002). Secondly, for some SDI considered, data was available only for urban agglomerations of more than 5000 people. Third, mostly larger cities have adopted SD strategies or plans that have reflected a lack of consensus from the point of view of goals and evaluation tools that justify the analysis of a potential consensual grid of SDI. Finally, Campbell (1996) recommended working at the city level because, at this scale, it is easier to determine the responsibilities of all parties involved, the actions are easier to control, while parties' contrasts are clearer or more clear-cut.

Of the 23 initial studies, three were specific to the field of transport, whereas three others had a limited range of indicators intended strictly to measure quality of life.[2] The final sample therefore consisted of 17 studies, covering cities or municipalities of various sizes (mainly larger ones) in the US, Canada and Europe. The main characteristics of the studies are described in Table 1, which yields two main findings. First, the 17 studies use between

[2] In fact, five studies addressed the concept of quality of life. However, only two of these studies used a sufficiently broad range of indicators to be considered as SDI. We therefore retained these two studies for this exercise, given our goal of comparing studies with similar objectives.

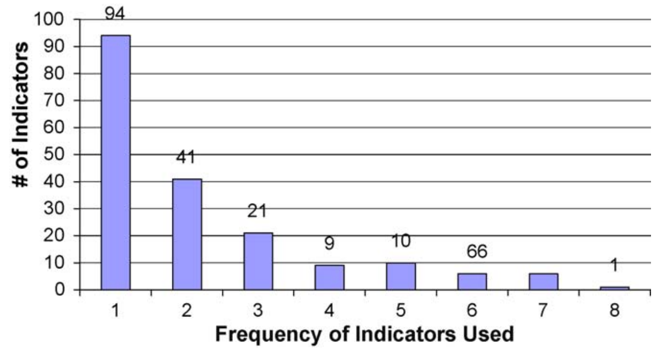


Fig. 2. Frequency of use of the 188 indicators.

10 and 86 SDI, which reveals a lack of consensus on the optimal number of indicators. In addition, studies involving a larger number of cities use fewer SDI. In the next section we will examine the factors that explain the variation in the number and choice of indicators.

From the 17 studies examined, we compiled 188 indicators. Because an indicator can be described or measured in different ways (e.g. atmospheric pollutants by toxicity, quantity emitted or CO_2 content), we ensured that the descriptions and units of measurement used allowed the definition of clear and distinct indicators. Indicators such as the average household income or the percentage of low income households thus represent different ways of characterizing household income for a given territory, and are considered as distinct indicators in our survey.

In addition, we observed the frequency of use of the 188 indicators noted. In total, 72% of the indicators apply to only one or two studies. Very few indicators are found in more than five studies. The results are shown in Fig. 2. These trends clearly reveal the lack of consensus on SDI, a phenomenon that is even more striking given that the 17 studies retained cover cities or urban centers of western countries that share many of the same values and characteristics.

In the third step, indicators were grouped according to the three classic components of sustainable development: economic, environmental and social, consistent with the classifications common to the 17 studies.[3]

Fourth, following this initial classification, 20 categories were formed in order to better structure the indicators within each component. We attempted to remain as faithful as possible to the classifications and categories suggested by most of the 17 studies. For example, the *transport* category includes all indicators related to transport in the environmental component. Similarly, the *education* category was assigned to the social component in order to group indicators that evaluate state, supply and demand in the field of education. The frequency of use of each indicator was then calculated for each component and category. The results are shown in Table 2. It is easily apparent that the environmental component is characterized by a large variety of indicators—hence a lesser consensus—whereas the social, economic and institutional components comprise indicators that are more consensual and therefore more frequently used.

Fifth, bearing in mind the subjective nature of the exercise, we performed a final classification of the 188 indicators, this time according to the classic components of sustainable development (i.e. without the institutional dimension). This distribution is illustrated in Fig. 3.

[3] As mentioned earlier, the institutional dimension was also considered within the social component. Section 4 of this article elaborates on the topic of indicators that overlap these components and the need to take their possible interaction into account.

This classification was intended to identify the indicators that overlap two or three dimensions, a situation often neglected in studies of SDI. However, as the Brundtland report (WCED, 1987) maintains, for development of a given territory to be considered sustainable it must be equitable, livable and viable.

Lastly, we noted the most frequently used indicators to extend the analysis and develop an approach to defining a parsimonious list, with fewer redundant indicators. Table 3 presents the 32 indicators that were used four times or more in the 17 studies in the sample. Of these indicators, 10 are strictly indicators of sustainable development that is indicators that identify a set of challenges that are concomitantly environmental, economic and social. The results are illustrated in Fig. 4a.

Based on these observations, the following section discusses variations in approaches and the lack of consensus on the choice and number of indicators.

4. Approaches and choice of indicators

Several authors have acknowledged the lack of consensus and formally established methods pertaining to SDI practices (see Legrand et al., 2007; Planque and Lazzeri, 2006). Difficulties in developing and applying SDI can be explained largely by the nature of sustainable development, whose very broad definition gives rise to multiple interpretations. Levett (1998) eloquently expressed this problem: "the struggle to find and use indicators of sustainable development is intimately bound up with the process of deciding what we mean by (the term) and what we shall do about it."

Following the analysis of the 17 studies retained, we discerned the main recurrent problems related to the effective use and choice of SDI, particularly in the municipal context. Notably, these problems lie in the definition of sustainable development, the objectives set by SDI and the constraints of accessibility of data used to create the indicators.

4.1. Diversity of approaches

Comparison of the 17 studies reveals that there are as many possible interpretations or approaches to creation of SDI as there are definitions of sustainable development. Similarly, depending on the objectives for the use of SDI, the approach varies between studies.

For instance, if some territorial practices associate sustainable development with the concept of quality of life (FCM, 2004; Jacksonville Community Council, 2004; Koller, 2006), others refer to more traditional dimensions (Cowley et al., 2007; Brazzini-Mourier, 2006; Planque and Lazzeri, 2006). In both cases, the definition of sustainable development is problematic. By emphasizing quality of life, an entire aspect of sustainable development (i.e. negative externalities) is not taken into account in the formulation of indicators. Thus, a given city or municipality may indeed promote a good quality of life for its citizens, yet this lifestyle may not necessarily be viable or equitable. For example, the indicators related to public services (e.g. recreation) may indicate a good quality of life while contributing to the sustainable development of a given municipality. Nonetheless, the municipal buildings that offer these services may consume large quantities of energy, which would indicate poorer performance from a sustainable development perspective. Moreover, by limiting sustainable development to "classic" dimensions, the classification of indicators may become problematic, particularly for indicators that reflect more than one-dimension at a time. This is the main criticism of the studies that have adopted this approach (Brazzini-Mourier, 2006; Koller, 2006).

Moreover, although it is important to create a proper hierarchy of objectives for which the indicators are used (Verry and Nicolas,

Table 2
Summary of frequency of use of indicators in 17 studies.

Sustainable development dimension	Category	# indicators in category	# of indicators used			
			One or two times	Three times	Four times	Five times or +
Environmental	Energy (excluding transport)	8	7	1	0	0
	Transport	25	20	2	2	1
	Air quality	15	10	3	0	2
	Noise	3	3	0	0	0
	Drinking water	7	4	2	0	1
	Green space, ecosystems and heritage	16	12	1	1	2
	Waste	5	3	0	0	2
	Other indicators[a]	6	3	2	1	0
	Sub-total	85	62	11	4	8
Social and institutional	Demographics	10	7	2	1	1
	Housing	18	15	1	1	1
	Education	11	7	2	1	1
	Security	5	4	0	0	1
	Health	9	8	1	0	0
	Well being	3	3	0	0	0
	Social and community services	11	8	1	2	0
	Governance	4	1	1	0	2
	Expenses and public administration	6	4	0	0	1
	Sub-total	77	57	8	5	7
Economic	Household income and expenses	13	8	1	0	4
	Employment	8	5	0	0	3
	Businesses	5	3	1	0	1
	Sub-total	26	16	2	0	8
Total		188	135	21	9	23

[a] Ecological footprints, natural catastrophes, level of exposure to natural and industrial risks, consumption of equitable products, urban intensification, and soil use.

2005), the objectives may also represent a break point in the use of SDI by playing a determining role in the approach retained. If most studies aim to integrate social, economic and environmental dimensions in the form of SDI in a general framework, others attempt to clarify one or more particular aspects by setting specific objectives or priorities (Tomalty, 2007; Jacksonville Community Council, 2004). In some cases, the objectives may even emerge from the identification of a particular challenge as a priority in a sustainable development perspective. For example, the *SMART Transportation Ranking Report* (Nemetz, 2007) strictly concerns transport and considers transport challenges to underpin problems related to sustainable development in large Canadian cities. Another example is the application of indicators in the field of *Sustainable Housing* (Winston and Eastaway, 2008), which considers the challenges related to housing as a priority in sustainable development. Even if such practices contribute to evaluating strengths, weaknesses and forecasts as part of an implementation strategy of sustainable development, they are admittedly not immune to political excesses of municipal administrations that define "their" objectives which "their" SDI must meet.

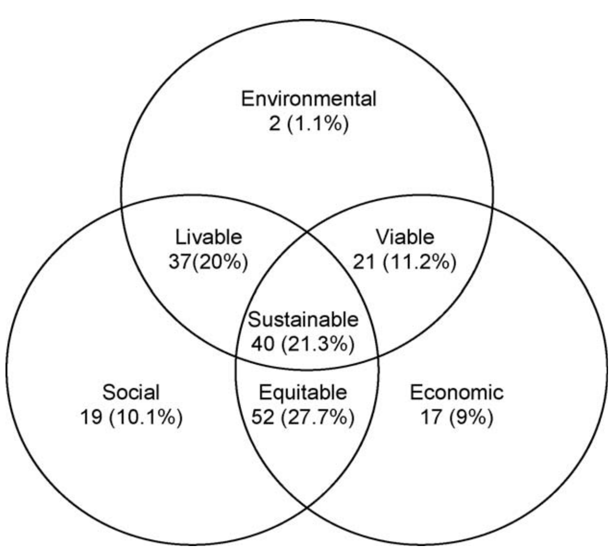


Fig. 3. Classification of 188 indicators counted.

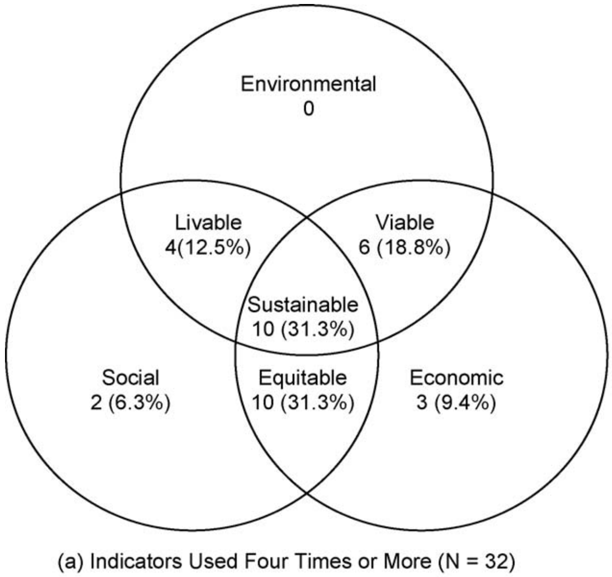
Therefore, we retain three important conditions that allow a less superficial approach to the design of SDI. First, sustainable development should not be systematically redefined when adapted to a particular territorial context. Moreover, the interpretations of SD should be consistent with the Brundtland report by reflecting the economic, social and environmental components as well as the overlaps between them. Second, the objectives regarding the origin and formulation of an SDI chart should reflect the existing tradeoff between consideration of specific factors for each city or municipality and the need to homogenize the indicators such that they allow a fairer comparison between municipal jurisdictions of the same stature. Concomitantly, these objectives must take into account the target audience and the ultimate use of the indicators as tools that support municipal sustainable development strategies.

We therefore believe that an effective approach would consist in identifying the integrated dimensions of sustainable development as broadly as possible, while ensuring that possible overlapping between these dimensions are clearly specified. In addition, the statement of objectives that SDI must meet should entail a social construction process that can be conditioned by social, historical, economic or local factors (Duchêne et al., 2002) without impeding the homogenization of measures that would allow comparison of territories of the same stature. This aspect deserves serious consideration, mainly to deter different territorial jurisdictions from creating "their own" indicators to meet objectives that they define. In the end, we emphasize comparability vs specific objectives for three main reasons. First, sustainable development policies and strategies are often established at the regional level (e.g. province). Therefore common indicators facilitate the monitoring of realized progress for the individual cities and/or for the regions themselves. In the end, the

Table 3
Indicators used four times or more in the 17 studies.

Frequency of use	Indicator	Description	Sustainable development dimension	Category
8	1. Unemployment rate	Unemployment rate of labor force	Equitable	Employment
7	2. Users of mass transit (MT)	Percentage of users of MT vs other means of transport	Sustainable	Transport
	3. Density of urban population	Density of population per square kilometre in urban areas	Sustainable	Demographics
	4. Quantity of waste	Quantity of household waste sent to landfills (tonnage per year)	Livable	Waste
	5. Crime rate	Crime rate per 100,000 inhabitants	Equitable	Security
	6. Mean or median household income per year	Mean/median household income ($ per year)	Economic	Income and expenses
	7. Job creation for all sectors combined	Number of new jobs per year for all sectors	Economic	Employment
6	8. CItizen participation in public affairs	Rate of participation in public hearings	Social	Governance
	9. Low income households	Households with income below $10,000 per year	Equitable	Income and expenses
	10. Concentration of PM10 particles	Average annual concentration in designated residential zones	Livable	Air
	11. Businesses with environmental certification	Percentage of businesses with environmental certification	Viable	Businesses
	12. Quantity of waste recycled	Quantity of waste recycled in tonnes/ inhabitant/year	Viable	Waste
	13. Daily water consumption per person	Average daily water consumption per person per year	Sustainable	Water
5	14. Households spending 30% or more of income on housing			
	Percentage of Households spending 30% or more of income on housing	Equitable	Housing conditions	
	15. GHG emissions (excluding transport)	GHG emissions in tonnes of CO_2 per year (excluding transport)	Viable	Air
	16. Quality of waterways	Percentage of waterways with excellent water quality	Livable	Ecosystem, heritage, green space
	17. SD policies or strategies	Absence or presence of political initiatives supporting sustainable development	Sustainable	Administration, public expendiures
	18. Rate of participation in municipal elections	Rate of participation in municipal elections	Social	Governance
	19. Participation rate for all sectors	Change in participation rate	Economic	Employment
	20. Ratio, population with high income–low income	Ratio of population with income over $80,000 to population with income below $20,000	Equitable	Income and expenses
	21. Population receiving social assistance	Percentage of workforce receiving social assistance	Equitable	Income and expenses
	22. Population aged 18 and over with less than a high school diploma	Percentage of population aged 18 and over with less than a high school diploma	Equitable	Education
	23. Space alloted to nature conservation relative to area of territory	Space alloted to nature conservation relative to area of territory	Sustainable	Ecosystem, heritage, green space
4	24. Average distance traveled per capita for all means of transport combined	Average distance in km/per capita/yr traveled for all means of transport combined	Sustainable	Transport
	25. Victims of traffic accidents	Rate of death and injuries caused by traffic accidents per 1000 inhabitants	Livable	Transport
	26. Green space per 1000 inhabitants	Percentage of urban space dedicated to green space per 1000 inhabitants	Livable	Ecosystem, heritage, green space
	27. Playgrounds (parks) per 1000 inhabitants	Percentage of urban space dedicated to playgrounds per 1000 inhabitants	Livable	Social and community services
	28. Cultural events	Annual number of cultural events	Social	Social and community services
	29. Average capacity of primary and secondary school classes	Average number of students per class at primary and secondary schools	Equitable	Education
	30. Diversity of new housing built	Proportion of housing starts for each type of dwelling	Equitable	Housing conditions
	31. Premature mortality rate	Ratio of deaths among people under age 75 per 100,000 inhabitants	Sustainable	Demographics
	32. Ecological footprint	Ecological footprint of municipality	Sustainable	Other

use of common SDI should lead to a better coordination of actions for cities within a given region (Thomas, 2002). Second, comparable SDI are important because they allow cities of the same size to have a common grid to share and apply successful tools and measures (Ambiente Italia Research Institute, 2003). Third, comparability and the adoption of common SDI is necessary to avoid that SDI become marketing tools for cities tempted by choosing indicators that make them look good only. We will take these facts into account to develop our approach to the creation of SDI in the next section of this article.



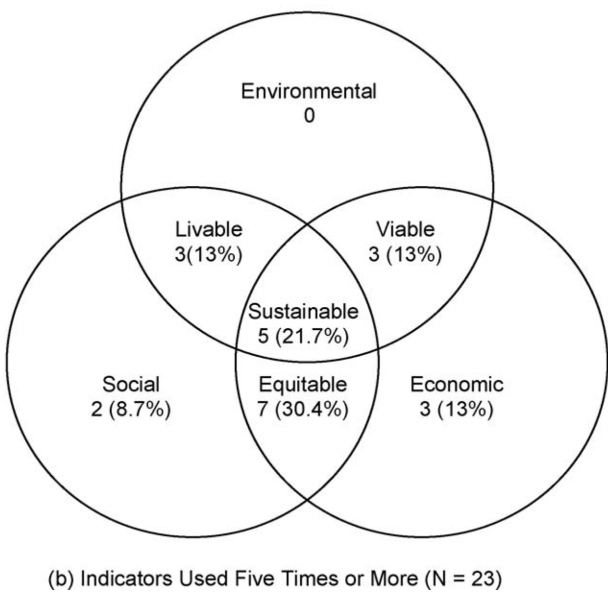


Fig. 4. Classification of most widely used indicators in 17 studies. (a) Indicators used four times or more ($N = 32$); (b) indicators used five times or more ($N = 23$).

4.2. Variation in the choice and number of indicators

Even when a similar approach is applied, we have observed that two studies or more may use indicators that vary considerably in number and attributes. As mentioned above, in the 17 studies examined, the number of SDI varies between 10 and 86, and the number of indicators related to the environmental component exceeds that of the other components, thus implying a lesser consensus.

We generally attributed these variations to the classification process that is the way the indicators are structured or organized in a given system, as well as to access constraints. Accordingly, we differentiate divergence between practices generally suggested by scientists and those endorsed by municipal administrations. If the latter tend to favor a less conceptual structure comprising fewer indicators, intended to achieve simple and quantifiable objectives, scientists prefer a minimum of aggregation and, if possible, simplification, in order to be faithful to the concepts. This contrast is illustrated in Fig. 5.

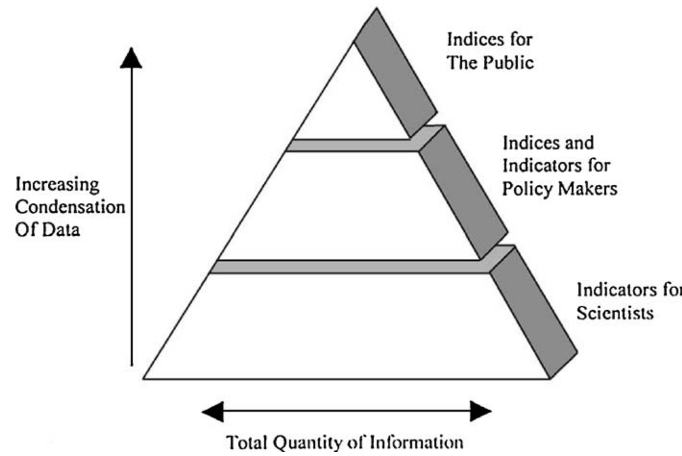


Fig. 5. The relationship between data condensation and audience (Shields et al., 2002).

Aggregating or simplifying information nonetheless reduces some of its analytical power while heightening the subjective nature of indicators (Verry and Nicolas, 2005). Kahn (2006) argues that there are still no standards pertinent and universal methods or criteria for aggregating and weighting SDI.

Moreover, all 17 studies examined acknowledge that the constraints of accessibility and availability of data are a recurring problem for municipalities. This situation occasionally dictates the use of less than maximally efficient indicators to capture sustainable development on the municipal scale. For example, bus speed may be put forth as an indicator of efficiency of mass transit (Basiago, 1999), whereas it has been demonstrated that cities where buses travel more quickly have greater sprawl coupled with less efficient and less used mass transit (Newman and Kenworthy, 1988)

Constraints of accessibility also affect the proportion of indicators in integrated components. Thus, although social and economic challenges take precedence in urban sustainable development (Federation of Canadian Municipalities, 2004), the popularity of related indicators is linked notably to the fact that qualitative and quantitative data (household characteristics, education, employment, etc.) are more accessible at the municipal scale than are data related to the environment (GHG emissions, energy consumption, air quality index, annual distance traveled per inhabitant according to travel mode, etc.).

5. SDI selection strategy

In this section we establish a strategy for choosing a list of pertinent indicators. This strategy is based on: (1) the definition of basic selection criteria derived from the tradeoff between parsimony and coverage of pertinent categories, and (2) the classifications and sorts that we previously analyzed in Section 1. Further, we consider the problems identified in Sections 3 and 4 when justifying our approach and validating our recommendations.

5.1. Selection criteria

Determining the optimal choice and number of indicators inevitably requires that selection criteria be defined. We evaluated the number of selection criteria used in the 17 studies. In total, more than half of the studies use fewer than three criteria, whereas one study identifies up to 14 selection criteria. Of a total of 68 criteria noted, only six are frequently used. The criteria are found under the following headings: "credible," "universality," "data requirements and availability," "comprehensible," "links with management" and "spatial and temporal scales of applicability."[4]

In addition, a growing number of authors recognize the importance of defining transparent and rigorous selection criteria to increase the value and scientific credibility of indicators selected while ensuring that they can inform decision-making processes (Belnap, 1998; Slocombe, 1998; Dale and Beyler, 2001; Niemeijer and De Groot, 2008). A particularly widespread approach in social sciences, perhaps owing to the simplicity of its acronym, is worth mentioning. An indicator must be SMART, namely:

> "Specific – be clear and concise and avoid vague terms; Measurable – quantifiable indicators to measure progress; Achievable (Assignable) – someone must be able to complete the objective; Relevant (Realistic) – able to be interpreted; within budget and time frame; Time-related – completed by a certain date; change measured by a certain date." (United Nations Statistical Institute for Asia and Pacific, 2007).

Even if the application of such an approach remains subjective, as Dale and Beyler (2001) note, it can be used to validate the choice and number of indicators. However, it should be considered as a complement to the adoption of clear objectives or the development of general principles. For example, the *Renewed EU Sustainable Development Strategy* rests on seven objectives and illustrates the holistic nature of the concept of sustainable development perfectly. Note that it applies selection criteria to supplement the objectives (on this subject, see Jones and Patterson, 2007). Similarly, the *International Institute* for *Sustainable Development* developed ten principles based on Agenda 21, and specified *a priori* selection criteria (see Hardi and Zdan, 1997).

5.2. Conceptual framework and classification method of indicators

Whereas a selection criteria chart can be used to produce a refined list of indicators, it is not sufficient to produce a structure or classification model justified by previously established objectives and by the processes and states to be measured.

The use of a conceptual framework is thus a fundamental step that can ensure that the indicators selected indeed cover the phenomena to be measured (Niemeijer and De Groot, 2008). There are no specific models that allow one to simplify or predict interactions that govern sustainable development (Abolina and Zilans, 2002). Further, there are many possible approaches to designing and organizing indicators, each of which has advantages and disadvantages (Hart, 1998).

The main conceptual frameworks are well documented by McLaren (1996). They include frameworks centered on objectives, challenges, sectors, components of sustainable development and cause and effect relationships; the latter are also known as "pressure-status-response" models (PSR). McLaren (1996) contends that although these approaches can meet the objectives for which they were designed, only the combination of two or more of these approaches can capture the complexity of sustainable development.

The PSR models and their derivatives (DPSIR: driving force-pressure-state-impact-reaction; DSR: driving force-state-reaction) are particularly useful. Such models combine different properties attributed to indicators. Niemeijer and De Groot (2008) and Barcelo (1999) propose definitions of these properties. Accordingly, the PSR model serves to group a series of indicators to represent anthropic pressure on the environment, the resulting state of the environment and the reactions or responses (political, actions, changes in behavior, etc.) to the problems encountered. In the DSR model, anthropic pressure on the environment is simply replaced by a driving force to better integrate social, economic and institutional indicators. In the DPSIR model, driving forces behind the use of transport or industry, for example, exert pressure on the environment such as emission of pollutants, which in turn degrade the state of the environment. This has an impact on human health and the ecosystem, which triggers a reaction by society in the form of political measures that can apply to each component of the model.

However, for such models to be effective, the number of indicators must be multiplied by three, four or even five. Each category of indicator (transport, energy, education, health, air, etc.) must be broken down into indicators of pressure, state and response in the case of a PSR model, for example. It is partly for this reason that the United Nations, which pioneered this type of approach in 1990, abandoned it in 2006. In addition, it does not allow attainment of the objectives for which the indicators were created (Bell and Morse, 2008). Lastly, there is no indication that increasing the number of indicators allows one to better capture the relative sustainability for one or more territories. On the contrary, as we mentioned in Section 3 of this article, the optimal number of indicators should consider the tradeoff between broad coverage of the sustainable development components and the goal of parsimony of indicators.

5.3. Survey-based selection strategy for SDI (SuBSelec)

In this section, we propose an optimal selection strategy of a subset of indicators from among the 188 indicators compiled. We then determine a general criterion of optimization along with the pertinent constraints. To do so, it is important to set clear fundamental guidelines for compiling the list of indicators. Evidently, the SDI retained should collectively cover the four components and 20 categories of sustainable development presented in Table 2. Whereas we could conceivably select all 188 indicators, we consider this a simplistic and inefficient strategy given redundancy factors and the loss of efficiency in the public dissemination of information and results.[5] A more targeted strategy would consist in retaining one indicator per each of the 20 categories defined. We could thus cover all components of sustainable development and all subcategories. Nonetheless, although this approach would reduce the number of indicators, it would ignore asymmetry in the importance and complexity of these components and categories. For example, Table 2 reveals that the *income and expenses* category tends to be particularly well represented in the studies. This is not surprising, and seems desirable given that it is useful to consider not only average income but also variance in the distribution of income (e.g. via percentages of low income). Thus it is worth representing all components and categories, although more weight should be given to certain items.

Once this initial analysis is accepted, three central elements emerge in the establishment of an optimal selection criterion for SDI. First, we are seeking a parsimonious list of SDI that is easily understandable and usable. This would allow us to simplify and synthesize the information to facilitate the dissemination of analyses. In addition, we aim to cover all the components and categories of sustainable development established in Table 2. Lastly, we endeavor to retain SDI on which a consensus exists in the literature. This point is crucial to establish solid conceptual bases in the development of indicators and indices. Ultimately, we are attempting to achieve a consensus to facilitate comparison

[4] To standardize the selection criteria used in the 17 studies, we adopted the classification developed by Niemeijer and De Groot (2008), using the categories whose definition corresponds to those found in the studies we analyzed.

[5] The latter element is important according to several lists of selection criteria, the best known of which is that of the 10 Bellagio principles. See Bell and Morse (2008).

Table 4
The 29 indicators retained.

Indicator	Description	Dimension of sustainable development	Category
SD policies or strategies	Absence or presence of political initiatives supporting sustainable development	Sustainable	Administration, public expendiures
Density of urban population	Density of population per square kilometre in urban areas	Sustainable	Demographics
Daily water consumption per person	Average daily water consumption per person per year	Sustainable	Water
Ecological footprint	Ecological footprint	Sustainable	Unclassified indicator
State of health reported by population	Percentage of people claiming that they feel well or very well	Sustainable	Health
Users of mass transit (MT)	Percentage of users of MT vs other means of transport	Sustainable	Transport
Space alloted to nature conservation relative to area of territory	Space alloted to nature conservation relative to area of territory	Sustainable	Ecosystem, heritage, green space
Cost of living	Cost of living in $ per person	Economic	Well being
Participation rate for all sectors	Change in participation rate	Economic	Employment
Job creation for all sectors combined	Number of new jobs per year for all sectors	Economic	Employment
Mean or median household income per year	Mean/median household income ($ per year)	Economic	Income and expenses
Households spending 30% or more of income on housing	Percentage of Households spending 30% or more of income on housing	Equitable	Housing conditions
Population aged 18 and over with less than a high school diploma	Percentage of population aged 18 and over with less than a high school diploma	Equitable	Education
Unemployment rate	Unemployment rate of the workforce	Equitable	Employment
Ratio, population with high income–low income	Ratio of population with income over $80,000 to population with income below $20,000	Equitable	Income and expenses
Population receiving social assistance	Percentage of workforce receiving social assistance	Equitable	Income and expenses
Low income households	Households with income below $10,000 per year	Equitable	Income and expenses
Crime rate	Crime rate per 100,000 inhabitants	Equitable	Security
Rate of participation in municipal elections	Rate of participation in municipal elections	Social	Governance
CItizen participation in public affairs	Rate of participation in public hearings	Social	Governance
Annual consumption of energy from renewable sources	Annual consumption of energy from renewable sources per inhabitant in kWh	Viable	Energy
Businesses with environmental certification	Percentage of businesses with environmental certification	Viable	Businesses
Quantity of waste recycled	Quantity of waste recycled in tonnes/inhabitant/year	Viable	Waste
Concentration of PM10 particles	Average annual concentration in designated residential zones	Livable	Air
GHG emissions (excluding transport)	GHG emissions in tonnes of CO_2 per year (excluding transport)	Livable	Air
Population exposed to Lnigh > 55 dB (A)	% of total population exposed to Lnight > 55 dB (A)	Livable	Noise
Quality of waterways	Percentage of waterways with excellent water quality	Livable	Ecosystem, heritage, green space
Quantity of household waste	Quantity of household waste sent to landfills (tonnage per year)	Livable	Waste
Participation in sports in parks and swimming pools	Number of participants as percentage of total population	Livable	Social and community services

between studies and cities over time[6]. Given these objectives, we have adopted the following general selection criterion:

Survey-based selection strategy for SDI (SuBSelec): a selection of SDI based on a review of studies intended to minimize the number of indicators selected from among those compiled, subject to the following constraints: (1) choose the most cited indicators; (2) cover the components of sustainable development and the pertinent predetermined categories and (3) choose the simplest SDI to facilitate data collection, understanding and dissemination.

5.4. Application of the strategy

Given the classifications and sorts performed above, the starting point of the selection process is to determine the most commonly used indicators. Three "characteristics" thus emerge from Table 3: 32 indicators are used four times or more, 23 are used five times or more and 13 appear six times or more. Based on our other selection constraints, it is clear that the 13 SDI used six or more times do not sufficiently cover the components and categories presented in Table 2. For instance, these SDI do not pertain to essential categories such as *education* and *housing*. By contrast, the 32 SDI used four times or more cover all of the components and categories. Thus, given the *SuBSelec* criteria defined above, to produce the list, indicators will be chosen from among those cited four times rather than those cited five times or more. In this case we will therefore choose between two typical situations found in studies using SDI. The first is the situation where a "high" number of SDI are used, to allow greater coverage of components and categories of sustainable development. This situation corresponds in this case to the 32 indicators cited four times. In the second situation, greater parsimony is favored at the expense of reduced coverage of components and subcategories of sustainable development. In this paper we refer to cases where 23 indicators are cited five or more times.[7] We thus aim to determine

[6] We are aware that the search for a consensus may create certain gaps and errors in the selection of indicators. We are not attempting to criticize or develop indicators, but rather to select a list that would be parsimonious and representative of knowledge at a given stage. However, we believe that the selection of indicators should be relatively consistent to allow a comparison over time. We will revisit temporal and spatial importance below.

[7] This type of situation is summarized well in the introduction of the work by Bell and Morse (2008).

whether it is optimal to add nine additional indicators to increase the coverage of components and categories. In other words, we will evaluate whether the gain in efficiency due to the information obtained through greater coverage of components and categories is superior to the loss of efficiency induced by a significant increase in the number of indicators used (39.1%). It is impossible to definitively answer this question objectively.[8] Nonetheless, two elements of the analysis indicate that it is preferable to use fewer indicators to the detriment of the coverage principle.

First, Table 2 reveals that the shift from indicators used four times or more ("four times") to those cited five times or more ("five times") leads to the non-representation of only two categories: *other* (e.g. ecological footprint) and *social and community services*. In all the other categories, the use of "four times" vs "five times" permits constant coverage. However, note that in addition to the items *other* and *social and community services*, four other categories are not represented in all cases, *namely energy*, *noise*, *health* and *well being*. Below we discuss a strategy for solving this problem.

A second factor argues in favor of the "five times" criterion. Fig. 3 depicts the 188 initial indicators in a classic Venn diagram of sustainable development. The purpose is to replicate Fig. 3 (in percentages), using much fewer indicators. In this case we used between 23 and 32 indicators. Fig. 4, which shows the same Venn diagrams for the "four times" and "five times" indicators, readily illustrates that the latter case is much more representative of the percentages obtained with the 188 initial indicators while covering the majority of the components. Therefore, we obtained the same type of coverage of components (in percentage) with 23 indicators as with 188. However, as mentioned above, by retaining only these 23 indicators, 6 of 20 categories would not be covered, namely: (1) energy (excluding transport); (2) noise; (3) other; (4) health; (5) well being; and (6) social and community services. Although these categories seem to be slightly more "secondary" in the studies, we believe that they should be represented by at least one indicator. To do so, we use the most prevalent indicator in the studies according to Table 2. For three of the six missing indicators, the problem is easily solved given that only one indicator stands out for the number of times it is used. For example, for the energy and health categories, no indicator is used five or more times, whereas only one indicator is used three or more times. We therefore use these singular indicators for the two categories. The same rationale applies to the "other indicators" category, for which only one indicator stands out in the column of indicators used four times. The three other categories not represented necessitate the choice of one indicator from among two or three. In effect, three indicators are used three times for the noise and well being items, while two indicators are used four times for social and community services. For each of these three categories we therefore choose the indicator for which the data are easiest to obtain.

We consequently obtained a list of 29 indicators, presented in Table 4. Fig. 6a illustrates a classic Venn diagram of sustainable development with the 29 indicators retained assigned to different groups and intersections. By comparing it with Fig. 6b, it is easy to see that the indicators retained allow similar coverage to the 188 initial indicators in terms of percentages of different components of the intersection of sustainable development: livable, equitable, viable and sustainable.

Thus, our parsimonious list of 29 indicators (Fig. 6a) reproduces the coverage of the integrated components of sustainable development ensured by the 188 indicators (Fig. 6b), particularly in the intersections of the environmental, social and economic components, namely livable, equitable, viable and sustainable. We summarize these correspondences in Table 5. The second column provides, for each of the intersections, the percentage of representation of the 188 SDI compiled. The third column contains the numbers corresponding to the 29 SDI retained that allow us to attain the same percentages of coverage as those obtained with the 188 initial SDI. Lastly, the third column provides the real numbers of SDI (from among the 29 retained) according to various intersections. It is therefore clear that the 29 SDI retained allow

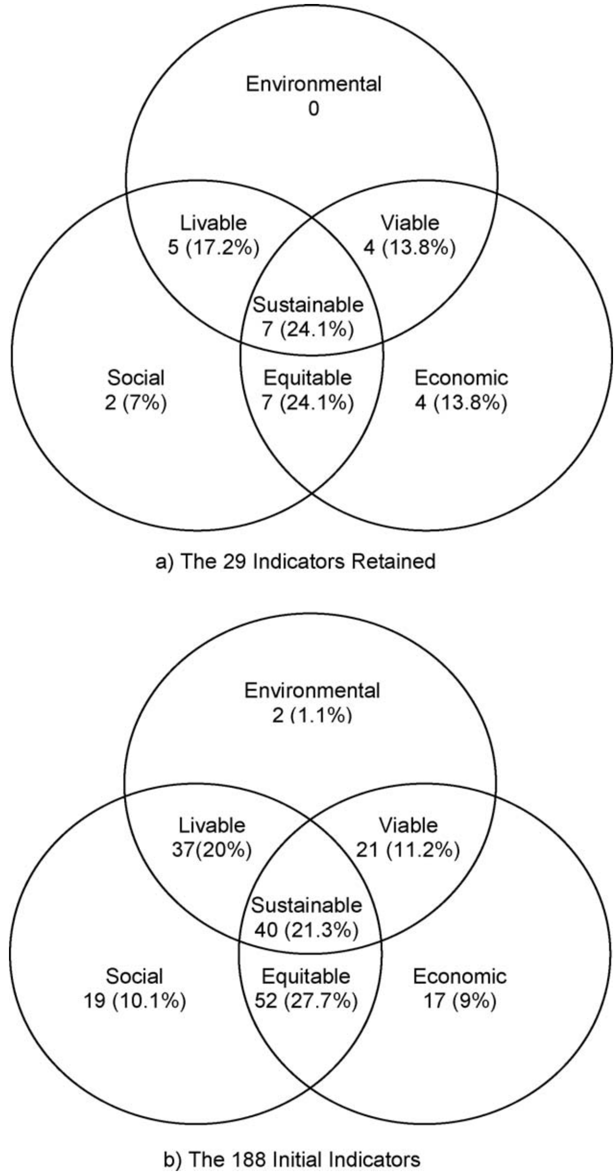


Fig. 6. Classification and count of 29 indicators retained vs 188 initial indicators. (a) The 29 indicators retained; (b) the 188 initial indicators.

Table 5
Percentage distribution of the 29 chosen indicators vs the percenrage distribution of the 188 initial indicators.

	% of distribution of 188 indicators	Corresponding numbers for all 29 indicators	Real numbers for distribution of 29 indicators
Livable	20	5.8	5
Equitable	27.7	8	7
Viable	11.2	3.2	4
Sustainable	21.3	6.2	7

[8] Aside from the fact that some find attempts to measure sustainable development illusory, the inherent unavoidable subjectivity is one of the main criticisms of the choice and use of SDI.

similar coverage to that obtained with the 188 compiled from the 17 studies examined.

6. Conclusion

From concept to local practice, ongoing debates increasingly underline the need to measure sustainable development SD based on indicators or evaluation criteria. One of the most common applications consists in comparing municipalities, notably to support local decision-making processes.

Problems related to the use and application of SDI primarily stem from (1) an overly broad definition of sustainable development that gives rise to multiple interpretations, (2) the absence of standard and universal classification methods or approaches to designing SDI, particularly at the municipal level, and (3) constraints caused by the accessibility of data that preclude their quantification and the specific qualification of indicators. These problems engender considerable diversity in the conceptual frameworks, choices and optimal number of SDI across the 17 studies examined.

In this article, we address these problems by applying a method based strictly on the empirical data found in the 17 studies that examined SDI. Accordingly, the main rationale of our approach is to find a method of selecting indicators that would allow the broadest possible coverage of the integrated components of sustainable development and the categories that comprise them, while minimizing the number of indicators retained.

This method, which we call *SuBSelec,* is a strategy that subjects the 188 indicators extracted from 17 studies to three parameters to reduce the number of indicators to an optimal level. This optimal level thus results from the union between the most frequently used indicators and those that maximally include the integrated components of sustainable development and their constituent categories. In total, 29 SDI were retained in our study, and clearly reflect the initial distribution of the 188 SDI through the integrated components of sustainable development.

Therefore, the *SuBSelec* method brings new perspectives to the debates related to the selection of urban SDI. We see it as a preliminary step in a selection process which aims to propose to planners and decision makers a scientifically based and operational SDI grid.

Although we recognize the subjective nature of our approach, we believe that the classification and categorization exercises can allow the selection of recognized and complementary indicators while covering the various aspects of sustainable development as broadly as possible. Moreover, we reach the same conclusion as Niemeijer and De Groot (2008) in that selection of indicators is invariably subject to arbitrary decisions at one stage of the process or another.

In addition, our analysis demonstrates that current practices related to SDI cannot meet standard objectives. Thus, considering the contradiction between the need to obtain indicators that allow comparison between jurisdictions and the desire to reflect local concerns, it is probable that consensus on certain SDI is a prerequisite to these objectives being met. Nonetheless, it should be acknowledged that this is a relatively new field that will surely benefit from ongoing and future local initiatives.

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