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MEASURING URBAN SUSTAINABILITY

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Developing new signals of urban performance is a crucial step to help cities maintain Earth's natural capital in the long term. Conventional measures of economic performance and urban quality of life are inadequate to capture the interdependence between urban society, economic development, and the environment. Furthermore, although cities affect and are affected by natural systems beyond their physical boundaries, the interdependence between urban systems and the regional and global environment is not reflected in urban decision-making. No signals on the state of natural resources and on the sustainability of their current uses are typically provided to urban communities.

Today local and national agencies are committing increased resources to create these signals by designing new strategies to report on the state of the environment (OECD 1991, 1993b; EEA 1995; WRI 1995). A number of communities have taken initiatives to develop sustainability indicators that will help them design and implement comprehensive plans (Alberti and Bettini 1996; Beatley 1995; MacLaren 1996). Furthermore, several international organizations have created specific programs to develop and harmonize urban indicators worldwide; these include the United Nations Centre for Human Settlements (UNCHS), the UN Commission on Sustainable Development, the World Bank, the Organization for Economic Cooperation and Development (OECD), the European Environment Agency (EEA), and the World Health Organization (WHO).

The task is, however, not simple. The challenge is to develop a new understanding of how urban systems work and how they interact with environmental systems on both the local and global scale. Three elements are part of this framework:

1. key variables to describe urban and environmental systems and their interrelationships;

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2. measurable objectives and criteria that enable us to assess these interrelationships; and
3. feedback mechanisms that enable the signals of system performance to generate behavioral responses from the urban community at both the individual and institutional levels.

The choices of which variables should be measured and which criteria should be used to measure them depend on how we define urban sustainability. Making these choices requires us to answer several complex and controversial questions that neither the social nor the natural sciences has yet resolved. Despite important recent progress in measuring urban environmental quality and performance, we known little about what makes a city sustainable. There is no consensus on how to define sustainability. Nor is there consensus on what city size, form, and spatial distribution of activities best facilitate the rational allocation of natural resources and minimize environmental impacts (Haynes 1986; Owens 1986; Newman and Kenworthy 1989; Gilbert 1991; Lowe 1991; Calthorpe 1993; Anderson, Kanaroglou, and Miller 1996; Crane 1996). Many urban analysts would argue that the interactions between urban form and natural processes cannot be understood in isolation from economic and social structures. Therefore, the concept of sustainability is hard to generalize. No single definition applies equally in all communities. Ultimately the way we see the course of actions to achieve sustainability is crucial in suggesting alternative approaches to measure progress.

In this article, I first examine various dimensions of urban sustainability. Using concepts from ecology, I define *urban ecological space* as the total natural capital and flows on which a city depends to meet the long-term needs of its inhabitants. Developing on this concept, I contend that indicators will not help address urban sustainability problems unless clear linkages can be established between urban patterns and the state of the natural resource base. I then analyze various approaches for designing urban indicators, proposed at the international levels, as well as a few examples at the local level. Finally, I discuss how best to structure the process for selecting indicators to ensure that the information collected is policy-relevant, scientifically founded, readily implementable, and usable for planning.

1. Urban Systems and Sustainability

The term sustainability as used here refers to a particular relationship between human and environmental systems—one that ensures meeting human needs in the long term (WCED 1987).[1] Holdren, Daily, and Ehrlich (1995) define a sustainable process or condition as one that "can be main-

[1] The term sustainable was first used in forestry and fisheries to refer to management strategies that keep harvests below the replacement rate (Vitousek and Lubchenco 1995).

tained indefinitely without progressive diminution of valued qualities inside or outside the system in which the process operates or the condition prevails" (p. 3). Although the concept has been the object of various interpretations and much discussion (Pearce, Markandya, and Barbier 1990), the debate has started to generate some areas of agreement or at least to delimit the areas of disagreement (Susskind 1995). There is agreement that for human activities to be sustainable, there must be a constant capital stock. There is also considerable consensus within the scientific community that humanity has altered important aspects of the natural resource base and that imprudent use may irreversibly reduce its capacity to support the human population in the future (Arrow et al. 1995).

A major area of contention is the degree to which manufactured capital can substitute for natural capital.[2] While neoclassical economists assume near-perfect substitution, ecologists stress that for some essential life-support systems, substitution is unlikely. According to John Pezzey (1992), sustainability is "non-declining utility," where utility is derived by aggregate stocks of natural and manufactured capital. In contrast, the Second Strategy for Sustainable Living defines sustainability as improving the quality of human life while living within the carrying capacity of supporting ecosystems (IUCN 1991). Ecological economist Herman Daly (1991) suggests three criteria to assess sustainability:

- Rates of use of renewable resources do not exceed replacement rates.
- Rates of use of non-renewable resources do not exceed rates of development of renewable substitutes.
- Rates of pollution emissions do not exceed the assimilative capacity of the environment.

When applied to cities, sustainability requires that inhabitants' needs be met without imposing unsustainable demand on local and global resources.The interdependence between cities and the global environment implies that even if cities reach sustainability at the local level, they will not necessarily be sustainable at the global level. Indeed cities may achieve good local environmental conditions in the short term by placing unsustainable demands on natural resources elsewhere and exporting their waste to other regions. It is only from a long-term perspective that the links between local quality and global sustainability become evident. Indeed these same cities will suffer from the effects of global environmental problems such as climate change, acidification, and stratospheric ozone depletion.

Today no cities can sustain themselves without drawing on the carrying capacity of their hinterland or region. Increasingly, the boundaries of the area of sources and sinks have extended far beyond their hinterland. A

[2] For a review of the ecological and economic paradigms on sustainability see Foeke and Kåberger 1993 and Rees 1995.

sustainable city is therefore not a totally self-reliant city. It is, however, a city that tends to be self-reliant. Indeed a city that depletes its resources base becomes less resilient and therefore more vulnerable to external stress. Developing the arguments of White and Whitney (1992), three conditions need to be met for a city to be sustainable: First, by adopting the best available technology, it must minimize its impact on natural resources. Second, assuming that a city has exceeded the carrying capacity of its hinterland and is importing carrying capacity from other regions, it must be based on an ecological surplus in these regions. Third, this same city should compensate the exporting regions for the value of ecological productive capacity it has subtracted. This means cities must recognize (1) the finite nature of the natural resources base upon which all urban activities depend, and (2) the needs of all people, not only the population living within the city boundaries, and future generations as well as the present one.

The Urban (Eco)system

The concept of urban ecosystems is helpful to investigate the relationships between urban systems and the environment (Figure 1).[3] Ecologists have described the city as an eterotrophic ecosystem, highly dependent on large inputs of energy and materials and a vast capacity to absorb emissions and waste (Odum 1953; Duvigneaud 1974; Boyden et al. 1981; Newcomb, Kalma and Aston 1978). Odum (1963) compared a hypothetical American city of one-million inhabitants and a density of 11.2 inhabitants per acre with the ecosystem of a comparable-sized lake of moderate fertility. He concluded that both the lake and the city require large watersheds, but the huge input of energy required to support urban activities has no counterpart in the lake system. In terms of energy metabolism, cities are "hot spots" on the biosphere's surface. Wolman (1965) used the term "urban metabolism" in a famous article in *Scientific American* to quantify the flows of energy and materials into and out of a hypothetical American city.

The Intergovernmental Program on Man and Bioshere (MAB), launched by UNESCO in 1970, developed an ecological approach to urban areas to help policymakers address the interdependence between urban systems and the environment. Boyden (1977), Newcomb (1978), Kneese and Bower (1979) have used this approach in studying various cities. Boyden et al. (1981) applied this concept in a comprehensive study of the metabolism of Hong Kong. Douglas (1983) described the equations to measure the energy, water, and material balances that constitute urban metabolism. All

[3] The concept is not new. Since 1925 with the work of Burgess and Park in Chicago, many urban analysts have used ecological analogies. The concept of the urban ecosystem has captured the attention of ecological scholars for more than three decades. See Odum (1963); Wolman (1965); Duvigneaud (1974); Stearn and Montag, eds. (1974); Boyden (1977); and Douglas (1983). Newcomb, Kalma, and Aston (1978); Kneese and Bower (1979), Boyden et al. (1981).

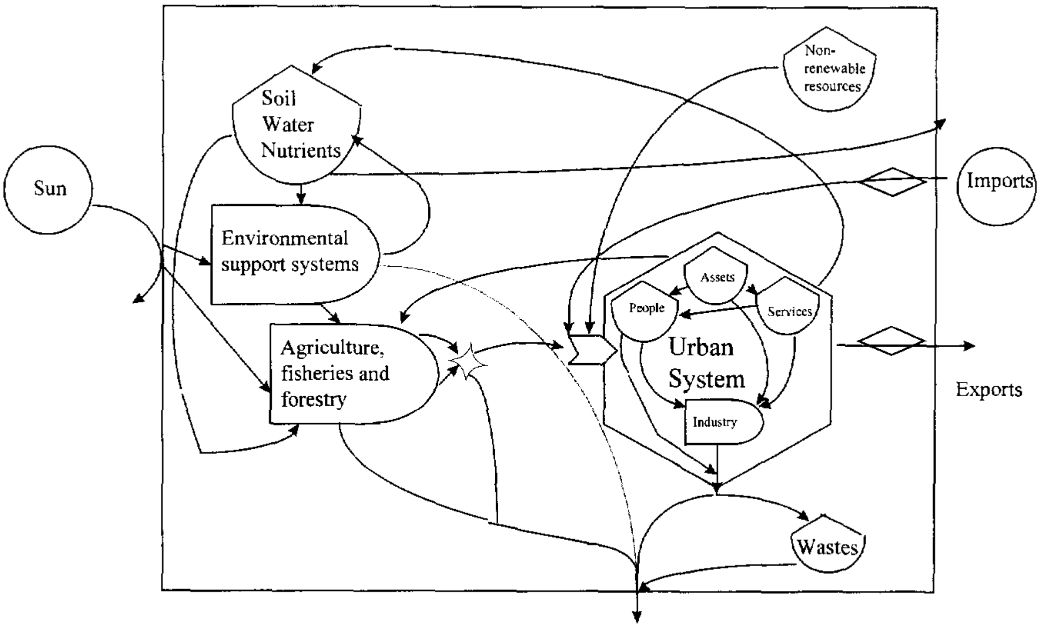


FIGURE 1. The urban (eco) system. Simplified model of the city as an ecosystem based on Odum TH (1983; 1994) systems ecology approach and energy circuit language.

these studies aimed to explain the mechanisms and processes that affect the sustainability of urban development and to facilitate the transformation of urban systems into "sustaining self-regulating systems."

The urban ecosystem approach has its limitations. Indeed, it cannot easily integrate biological and socioeconomic concepts into a unified analytical framework. Douglas (1983) sees several problems: "The complexity of the variables involved, the contrasting scales of measurement by which these variables are assessed and the inapplicability of positive procedures for the analysis of some behavioral and societal variables" (p. 16). These difficulties have prevented achieving a true integrated approach in the study of Hong Kong and ultimately limited the development of a theory of urban ecology.

However, the ecosystem is a powerful concept for dealing with very complex systems (Lynch 1981). Lynch (1981) suggests that a "learning ecology" might be more appropriate for human settlement, since "some of its actors, at least, are conscious, and capable of modifying themselves and thus of changing the rules of the game" (p. 115), for example restructuring materials and switching the path of energy flows.

In the following sections, I identify the key ecological functions that need to be maintained to sustain an urban setting in the long term and the dimensions and performance criteria that need to be considered in evaluating whether urban trends are moving towards or away from sustainability.

Urban Ecological Space

Cities alter the local and the global environment in several ways. First, cities occupy and modify space. Second, they import vast quantities of food, water, and energy and export emissions and waste. Moreover, cities depend on a variety of subsystems that each rely on several local and global ecological functions and services. A systematic analysis of urban sustainability should consider the following aspects:

1. direct transformation of the physical structure and habitat;
2. use of natural resources (renewable and non-renewable);
3. release of emissions and wastes; and
4. human health and well-being.

In thermodynamic terms, cities are open systems dependent on energy and matter imported from the ecosphere. From this perspective cities can be considered dissipative structures: self-organizing nonequilibrium systems that maintain their internal order (neg-entropy) at the expense of increased disorder (entropy) at higher levels of the systems' hierarchy (Prigogine 1954; Nicolis and Prigogine 1977).

To measure urban sustainability, I define *urban ecological space* as the total natural capital and flows on which a city depends to meet the long-term needs of its inhabitants. This capital includes both the sources and sinks, as well as the ecological support systems and services they provide to the human population (Figure 2). I draw on the notions of *carrying capacity* (Odum 1963; Richlefs 1990; Daily and Ehrlich 1992; Meadows, Meadows, and Randers 1992), *environmental space* (Weterings and Opschoor 1993; Opschoor and Costanza 1994; Wackernagel and Rees 1995), *ecological footprint* (Rees 1992; Rees and Wackernagel 1994; Wackernagel and Rees 1995), and *appropriated ecosystem area* (Folke, Larsson, and Sweitzer 1994) to express the idea that given the finite nature of Earth's ability to sustain human life, cities can import carrying capacity from other regions only if they are importing other regions' ecological surplus.

What distinguishes the notion of urban ecological space from the notions proposed by previous scholars is the consideration that the city is an organized system of many interacting biophysical and socioeconomic components and that the system itself affects the level of pressure that individuals exert. Whether a city's inhabitants choose a private or public transportation system to commute between home and work depends, among other considerations, on the availability of an efficient public transportation system. This, in turn, hinges on the implementation of numerous collective decisions to manage urban growth and invest in public transportation.

The production of waste and their management are other examples of how the infrastructure in cities affects the impact that individuals exert.

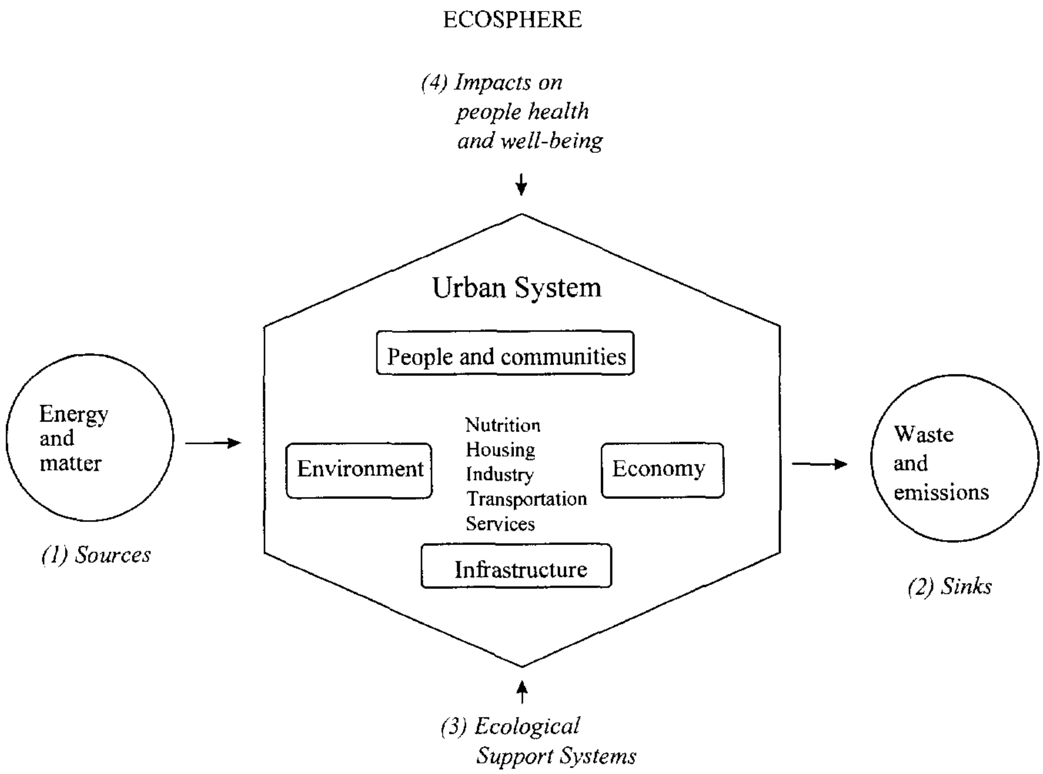


FIGURE 2. (1) Urban ecological space (UES) using WRI (1995) framework—four categoreis of indicators can be identified. Sources include natural resources stocks and flows. (2) Sinks are the capacity of ecosystems to absorb pollution and waste. (3) Ecological support systems are life support services ranging from climate regulation and nutrient recycling to the maintainance of biodiversity. (4) Impacts on human health and well-being are the direct effects on human population through polluted air, water, food etc.

While part of a product life cycle—what goes into the product—is determined at the production level, another important part—how much and what goes to waste disposal—is decided at the consumption stage. The latter depends on specific practices in different communities for recycling and collecting waste as well as on specific requirements for waste treatment and disposal.

The urban ecological space is then the carrying capacity of a specific urban ecosystem—the number of people that it could support indefinitely without impairing the capacity of Earth to support the human population in the future. While there is great controversy on whether we can actually measure carrying capacity (Holling 1977; Daily and Ehrlich 1992) and whether this measure is useful to policymakers (Godschalk and Parker 1975; Godschalk 1977), there is increasing consensus that there are biophysical limits to economic growth and that trade-offs need to be made. By measuring the urban ecological space, we can explore how some urban structures make such trade-offs more efficiently than others.

Dimensions of Urban Sustainability

In measuring urban sustainability, we are interested in both the *quality* of urban systems as well as the *impact* that cities exert on both the local and global resource base. From an ecological perspective, the interaction between urban systems and the environment can be described by indicators of sources, sinks, ecological support systems, and human health and welfare. The challenge is to relate the ecological space appropriated by cities to trends in urban patterns. A useful set of indicators should be able to tell us both (1) whether urban quality and performance in cities is improving or deteriorating in relation to certain sustainability criteria or desirable targets, and (2) how these trends in urban quality and performance are linked to trends in spatial structures, urban organization, and lifestyles.

Urban and environmental systems are so tightly interrelated that they make any classification of their interrelationships quite arbitrary. Multiple levels of explanation need to be taken into account when examining their interdependence. Though they may be all accurate, each level of explanation provides a new level of information. I have identified three dimensions that need to be considered in measuring urban sustainability: (1) urban quality (2) urban flows; and (3) urban patterns. While each of these dimensions would require extensive elaboration, here I limit my focus on the linkages between these dimensions and the natural resource base. For each of these dimensions, indicators can be specified as symptoms or causal factors affecting sustainability. The major categories of indicators are summarized in Figure 3.[4]

Urban Quality

The quality of the urban environment depends on physical elements and socioeconomic conditions as well as on the culture and values of urban communities. Building upon Kevin Lynch's (1981) performance dimensions, proposed in *Good City Form,* I suggest seven criteria of urban quality crucial to sustainability. First, urban life requires good environmental quality —clear air, water, and soil—but also adequate food supplies, housing, and infrastructure, as well as green areas and open space. These elements are dependent on the availability of natural resource stocks as sources, sinks, and ecological support systems—on which human health and welfare depend. Furthermore, to be sustainable, resource allocation must be both efficient—maximize the economic output per unit of resource input—and

[4] I discuss a first version of this approach in Alberti, Solera, and Tsetsi (1994). I test a simplified version of this framework in an analysis of 72 European cities in preparation of the EEA (1995) report *Europe's Environment*, Chapter 10: The Urban Environment.

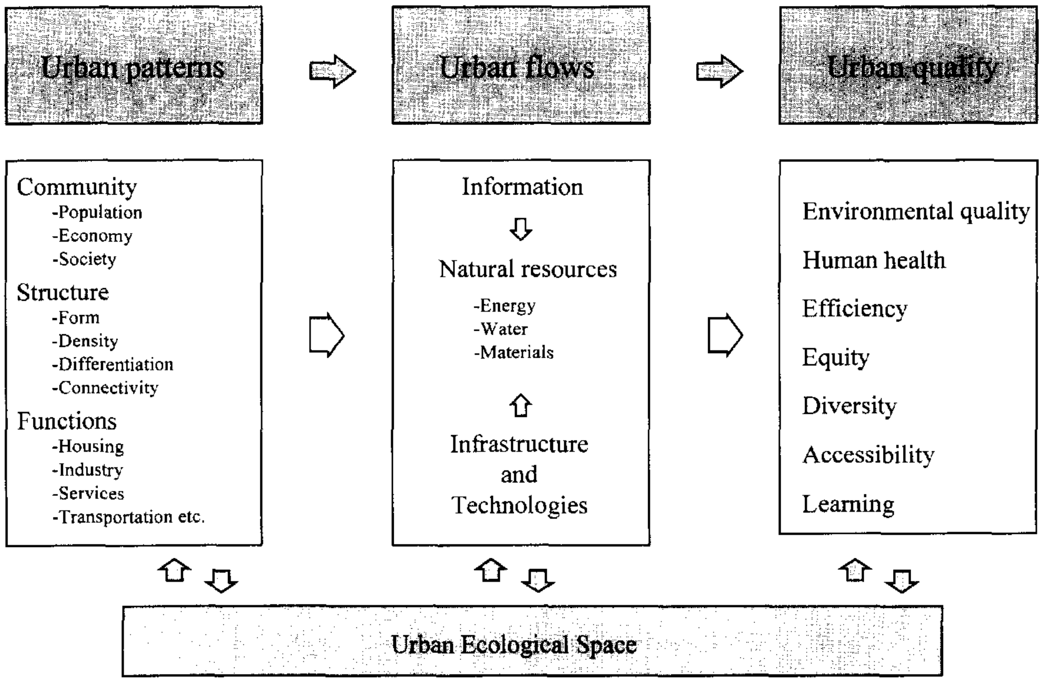


FIGURE 3. Urban sustainability dimensions.

equitable —maximize social benefit per unit of economic output—across social groups, regions, and generations. While generally considered in opposition, efficiency and equity considerations are complementary to sustainability. Indeed, local efficiency in the short term can be achieved by transferring costs to other communities or other generations, but it will affect the sustainability of the same community in the long term.

In urban systems, the diversity of actors—in terms of communities' cultures and individual behaviors—as well as the diversity of the built and natural landscapes—in terms of forms and functions—are crucial to their flexibility and adaptability to continuous change and to their resilience. Furthermore, accessibility in urban settings is crucial to sustainability. It is increasingly recognized that when people lack access to essential resources and services they impose greater impact on the local and global environment. Urban sustainability, then, can be achieved only if other objectives such as nutritional security, health protection and safety, and greater access to resources and services are met. A final criteria that characterizes a sustainable city is its ability to learn and modify its behavior—both at the community and individual level—in response to environmental change.[5]

[5] For a discussion on the seven criteria of urban quality—(1) environmental quality; (2) human health; (3) efficiency; (4) equity; (5) diversity and flexibility (6) accessibility and control; and (7) learning—see Alberti et al. (1994).

In the past, most urban indicator programs have focused on the quality of the physical environment, defined as meeting specific standards for the quality of the air or of drinking water and standard requirements for land use, built-up areas, and green space. Today there is increasing evidence that the quality of the environment is not necessarily achieved through the sum of sectoral qualities and that the physical environment is only one element of a more complex whole. Furthermore, it is increasingly recognized that people's perceptions and values are an integral part in the urban context. Urban quality is a combination of tangible and untangible. As Kevin Lynch (1981) points out, we cannot establish an optimal city size, ideal density, or ideal daytime temperature since situations and values differ. In the same way the concept of sustainability is hard to generalize. What we can try to generalize are certain measurable performance dimensions that can relate the spatial form of a city to human purposes and values. The problem is how to take these purposes and values into account in evaluating the quality of human settlements. Indeed while the task of defining objective measures of physical qualities is relatively easy, we know little about how to incorporate the subjective dimension in valuing them. It is clear, however that any complete model of urban sustainability must integrate both.

Urban Flows

The impact of cities on the environment can be examined by analyzing the flows of natural resources that support their activities. One challenge in measuring sustainability is to select a few measures of urban impact that account for the ecological space appropriated by cities. Several approaches have been proposed. Odum (1983, 1994) analyzes the urban energy balance in terms of energy flows—the energy requirements for the support of urban life and the energy lost from life-support systems. Douglas (1983) provides formal equations to measure the urban energy balance, the water balance, and the material balance (Table 1). Both these approaches provide extremely useful signals on the state and trends of the system, and they guide us in identifying the complex elements that drive these trends.

More recently, Rees and Wackernagel (1994, 1995) have proposed the concept of *ecological footprint:* the ecological productive areas required to support the population in a given urban region (see article in this issue). They estimate Vancouver's ecological footprint at 207 times the geographic area of the city. In a similar study, the International Institute for Environment and Development (1995) reported that London appropriates an area 120 times greater than administrative London, considering only the inhabitants' consumption of food and forest products, and its capacity to assimilate emissions of carbon dioxide. Using a different approach, Folke, Larsson, and Sweitzer (1994) estimate that the *appropriated ecosystem area* required

TABLE 1. Urban Metabolism Equations (Douglas 1983)

The surface urban energy balance equation is described as follows:

$$Q_S+Q_F+Q_I=Q_L+Q_G+Q_E$$

where
Q_S = Rate of arrival of radiant energy from the sun
Q_F = Rate of generation of heat due to combustion and dissipation in machinery
Q_I = Rate of heat arrival from the earth's interior
Q_L = Rate of loss of heat by evapotranspiration
Q_G = Rate of loss of heat by conduction to soil, buildings, roads, etc.
Q_E = Rate of loss of heat by radiation.

The water balance is written as follows:

$$P+D+A+W=E+R_S+S$$

where:

P = Precipitation
D = Dew and hoar frost
A = Water released from anthropogenic resources
W = Piped water
E = Evaporation
R_S = Natural and piped surface and sub-surface flow out of the city
S = Change in water storage in the urban fabric.

The urban material budget can be expressed as follows:

$$M_s=M_o+W_f+W_a+M_c+M_t$$

Ms = Quantity of materials supplied to the city
Mo = Materials exported from the city
Wf = Solid and liquid waste materials
Wa = Atmospheric pollutants discharged from the use of materials
Mc = Material converted through heat production or other processes
Mt = Net addition of materials to the urban fabric and stock.

to supply renewable resources to 29 major cities in the Baltic Sea drainage basin is 200 times larger than the areas of the cities themselves.

While these aggregate measures are crucial to recognize the direction of urban trends, more disaggregated measures are required if planners should be able to interpret urban change and design strategies to achieve sustainable urban patterns.

Urban Patterns

To analyze the interactions between urban systems and the environment, we can focus on the trends in the quality of the environment in cities or on their impacts on natural resources. But to understand these interactions, we need to examine how cities work and how their spatial structure, urban organization, and lifestyles affect their quality and performance. Yet current approaches to developing urban indicators have paid little attention to

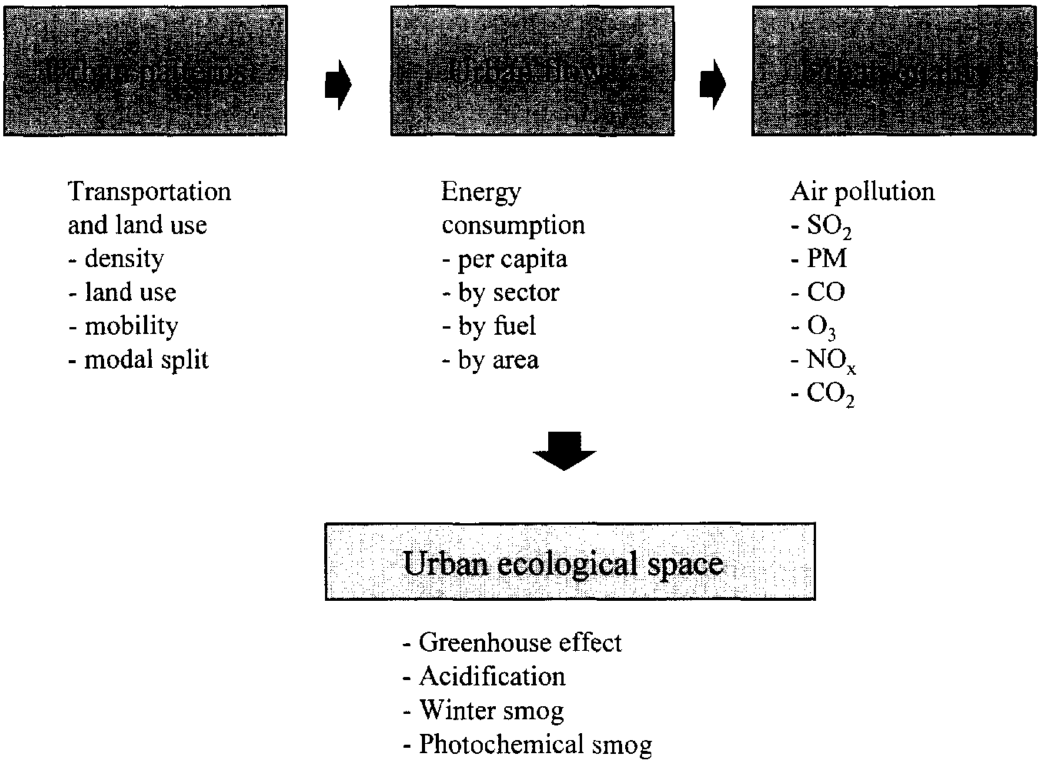


FIGURE 4. Example of urban indicators.

monitoring urban patterns in relation to local and global environmental trends. This information would be crucial to guide urban planning and management towards sustainability. Not only would it provide a basis to assess urban trends; it would also improve our understanding of how urban patterns affect cities' environmental quality and performance.

Consider, for example, the linkages between air quality, energy consumption, and transportation patterns. The variables selected to monitor these factors are specified in Figure 4 and are classified according to three categories of indicators (1) urban quality, (2) urban flows, and (3) urban patterns. Trends in air pollution at the local and global scales can be described by selected indicators of emissions of local pollutants, acidification substances and greenhouse gases.

From available statistics (UNEP/WHO 1992; OECD 1994; EEA 1995), we can summarize three main trends in urban air pollution:

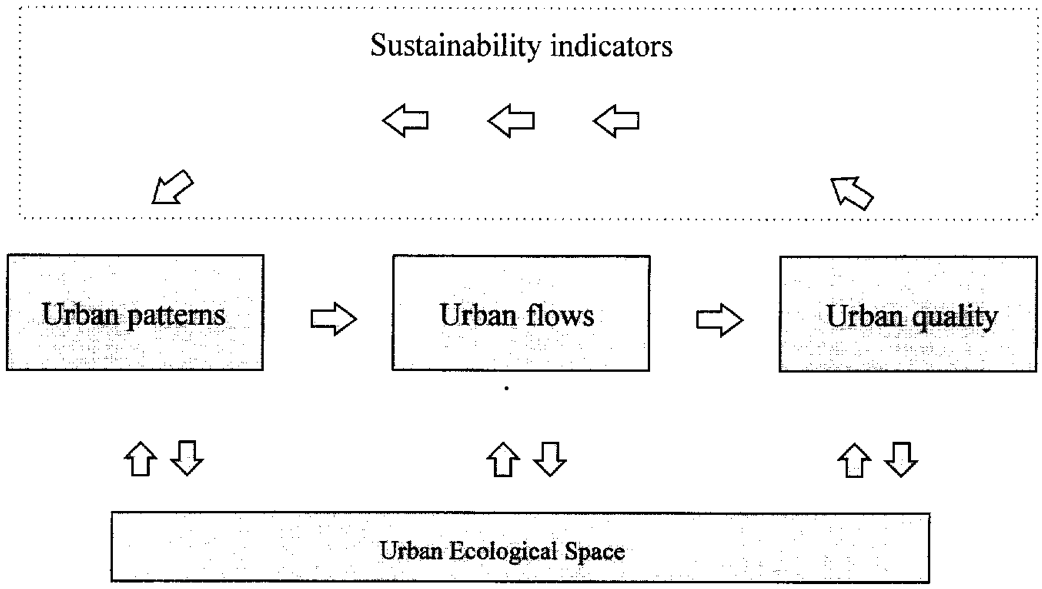
1. Emissions of most conventional atmospheric pollutants such as sulphur dioxide (SO_2), particulate matter (PM), and lead (Pb) have dropped drastically in the majority of cities in developed countries, but remain critical in most developing countries and particularly in the largest urban agglomerations such as Beijing, Mexico City, and Seoul.

2. Emissions of traffic-related pollutants such as nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) are increasing in the cities of most developed countries.
3. Per capita carbon dioxide (CO_2) emissions have increased in most developed cities.

Local high-level air pollution has been reduced in the cities of developed countries by implementing air quality standards. In the majority of these cities, two changes have dramatically reduced the concentration of sulphur dioxide and particulate matter: using natural gas for domestic heating instead of coal and oil, and relocating industries out of city centers. However, emissions of nitrogen oxides and CO_2 are at a critical or increasing levels in most cities.

Since sources of air pollution involve primarily the combustion of fossil fuels, and therefore the production and consumption of energy, urban air pollution trends reflect energy patterns across cities; particularly the increasing importance of the transportation sector as a consumer of energy. A study on London energy use, for example, shows that between 1965 and 1990 the percentage of energy consumed by the industrial sector declined by 15 points; meanwhile the energy consumed by transport increased by 11 points (LRC 1993). An analysis of urban energy consumption by sector in a number of cities in Europe (EEA 1995) and North America (ICLEI 1993) shows that the domestic sector is the largest consumer of energy, using more than one third of total energy. Transport comes second, using up to 30%, and its importance is increasing. Commercial and industrial uses vary considerably according to cities' economic structures. Air pollution and energy trends are also consistent with transportation and land-use patterns. Indeed, while there is sharp disagreement on how the urban structure affects transportation trends (Anderson, Kanaroglou, and Miller 1996; Crane 1996), it should come as no surprise that the density and location of urban activities influence mobility and that the public transportation infrastructure affects people's choice of mode of transport (Gilbert 1992; Newman and Kenworthy 1989; Lowe 1991; White 1994; OECD 1993). Both these elements influence energy consumption and the rate of air pollutant emissions into the environment. According to a recent OECD/ECMT (1993) survey, whether cities are growing or declining in population size, all are experiencing a decentralization of both population and jobs out of central areas.

The crucial point here is that the changes observed in air quality, energy consumption, and transportation patterns are consistent with a larger trend: cities are now appropriating ecological space on a global rather than a local scale. This leads me to conclude that most cities have responded to signals given by environmental regulations. Indeed, we can credit these regulations for the dramatically improved urban air quality in developed countries over



the last two decades. But if the signal is incomplete or incorrect, the response will not resolve the problem. It will merely shift the problem either to another region or to the next generation. To monitor sustainability we need to redefine the urban ecological space and carefully choose signals that can link urban patterns to the state of the resource base (Figure 5).

2. Urban Indicators

Urban indicators are crucial to help local and national policymakers improve their action towards sustainability. They serve several purposes: (1) systematic monitoring of urban environmental changes, (2) early warning of urban environmental problems, (3) target setting, (4) performance reviews, and (5) public information and communication. Indicators provide information in a form that facilitates communication among experts, policymakers, and the public. By simplifying a vast amount of information into a simple form, they make it much easier to read and understand. On the other hand, since indicators are models of reality, they allow us to relate a simple measure, such as the level of emissions of a particular atmospheric pollutant, to complex environmental phenomena, such as acidification or climate change. In addition, environmental indicators provide a measure of trends in the state of the environment and allow policymakers and the public to assess policy performance over time (WRI 1995).

In this section, I first examine the progress made at the international level in order to select urban environmental indicators. Using the framework proposed above I examine the lists of indicators proposed by six international organizations: UNCHS and the World Bank, UNCSD, OECD, EEA, and WHO. I compare these efforts with the tendencies emerging at the local scale. Later I discuss how these elements can be brought together to help create a widely accepted set of urban sustainability indicators.

Conceptual Models

The lists of urban indicators that public agencies have selected differ, quite naturally, in their policy focus and geographic scale, since they respond to different purposes for measuring. They also respond to various, implicit or explicit, models of the interactions between environmental and human systems. The United Nations Center for Human Settlements (UNCHS) and the World Bank (1995) have defined the broadest set of objectives for the urban indicator program:

1. to identify a set of key urban indicators for measuring a city's performance and for developing urban policies;
2. to help countries harmonize indicator frameworks and prepare their national reports;
3. to assist national and regional efforts to develop indicators through training programs, survey design, and data definition and assembly; and
4. to implement a permanent data-collection infrastructure and database to allow systematic assessment of the state of human settlements and the effects of urban policies.

The UNCHS indicators are developed around key issues (Table 2). Indicators selected exemplify a set of norms for seven policy sectors from the point of view of key stakeholders or players in the arena. From these norms UNCHS and the World Bank have derived a number of objectives and then selected indicators to help evaluate the policies designed to meet these objectives. The background document refers to a "well-functioning city" as the result of "well-functioning" sectors, and classifies indicators into seven categories: (1) socioecomonic development, (2) infrastructure, (3) transport, (4) environmental management, (5) local government, (6) affordable and adequate housing, and (7) housing provision. In addition, the UNCHS Indicator Program includes a background-data module, which provides selected demographic indicators.

The UN Commission on Sustainable Development (1996) is currently coordinating efforts to develop sustainability indicators as one step in monitoring sustainable development as defined in Agenda 21 (Table 3). While relevant at the urban scale, UNCSD indicators are primarily national in scope. In the same way, the scope of the urban indicators proposed by the OECD (1991, 1993, 1994), is delimited by the focus on national economic

TABLE 2. UNCHS Indicators

MODULE 0. BACKGROUND DATA

Indicator D1: Land use
Surface of land (sq. km) in the urban agglomeration and/or in the metropolitan area used for: a) residential; b) business; c) agriculture; d) transport; e) recreational; f) vacant; g) water.

Indicator D2: Population
Total population by sex in: a) the city proper; b) the metropolitan area; c) the urban agglomeration; d) the country as a whole.

Indicator D3: Population growth rate
Annual population growth rate.

Indicator D4: Woman headed households
Total number of households headed by women.

Indicator D5: Average household size
Average number of persons per household.

Indicator D6: Household formation rate
Annual rate of growth of households.

Indicator D7: Income distribution
Percentage of households and average household income by quintiles.

Indicator D8: City product per person
City product divided by population.

Indicator D9: Housing tenure type
Number of households in the following tenure categories: a) owned; b) purchasing; c) private rental; d) social housing; e) sub-tenancy; f) rent free; g) illegal; h) other.

Urban Indicators

MODULE 1. SOCIO-ECONOMIC DEVELOPMENT

Indicator 1: Households below poverty line
Percentage of households situated below the poverty line, by sex of household head.

Indicator 2: Informal/undeclared employment
Percentage of the employed population whose activity is part of the informal sector.

Indicator 3: Hospital beds
Number of persons per hospital bed.

Indicator 4: Child mortality
Proportion of children who die before reaching their fifth birthday, by sex.

Indicator 5: School classrooms
Number of school children per classroom per school in: a) primary schools; b) secondary schools.

Indicator 6: Crime rates
Number of reported crimes annually per 1000 population, for: a) murders; b) thefts.

MODULE 2. INFRASTRUCTURE

Indicator 7: Household connection levels
Percentage of households connected to: a) water; b) sewerage; c) electricity; and d) telephone.

Indicator 8: Access to potable water
Percentage of households with access to potable water

Indicator 9: Consumption of water
Average consumption of water in litres per day per person, for all uses.

(continued)

TABLE 2. *continued*

Indicator 10: Median price of water, scarce season
Median price paid per hundred litres of water in US dollars, at the time of year when water is most expensive.

MODULE 3. TRANSPORTATION

Indicator 11: Modal split
Proportion of work trips undertaken by: a) Private car; b) Train or tram; c) Bus or minibus; d) Motorcycle; e) Cycling; f) Walking; g) Other

Indicator 12: Travel time
Average daily time in minutes for a work trip.

Indicator 13: Expenditure on road infrastructure
Per-capita expenditure in US dollars on roads (three year average).

Indicator 14: Automobile ownership
Number of automobiles per 1000 population.

MODULE 4. ENVIRONMENTAL MANAGEMENT

Indicator 15: Percentage of wastewater treated
Percentage of all wastewater undergoing some form of treatment.

Indicator 16: Solid waste generated
Solid waste generated per person, in cubic metres and in tonnes per annum.

Indicator 17: Disposal methods for solid waste
Proportion of solid wastes disposed: a) to sanitary landfill; b) incinerated; c) to open dump; d) recycled; e) other.

Indicator 18: Regular solid-waste collection

MODULE 5. LOCAL GOVERNMENT

Indicator 20: Major sources of income

Indicator 20.1: Local government per-capita income: Total local government sources of funds in US dollars annually, both capital and recurrent, for the metropolitan area, divided by population (three year average).

Indicator 20.2: Percentage of local government income by source: a) Taxes; b) User charges; c) Other own-source income; d) Transfers from higher levels of government; e) Borrowings; f) Other income.

Indicator 21: Per-capita capital expenditure
Capital expenditure in US dollars per person, by all local governments in the metropolitan area, averaged over the last three years.

Indicator 22: Debt service charge ratio
Total principal and interest repaid, including bond maturations, as a percentage of total expenditure by local governments.

Indicator 23: Local government employees
Total local government employees per 1000 population.

Indicator 24: Personnel expenditure ratio
Proportion of recurrent expenditure spent on wage costs.

Indicator 25: Contracted recurrent expenditure ratio
Proportion of recurrent expenditure spent on contracted activity.

Indicator 26: Government level providing services
Urban services delivered to the population by type of service and type of supplier ("check boxes" indicator).

Indicator 27: Control by higher levels of government
Independence of action of local government ("check boxes" indicator)

TABLE 3. UNCSD Working List of Indicators of Sustainable Development

Chapters of Agenda 21	Driving Force Indicators	State Indicators	Response Indicators
		Category: Social	
Chapter 3: Combating poverty	Unemployment rate	Head count index of poverty Poverty gap index Squared poverty gap index Gini index of income inequality Ratio of average female wage to-male wage	
Chapter 5: Demographic dynamics and sustainability	Population growth rate Net migration rate Total fertility rate	Population density	
Chapter 36: Promoting education, public awareness and training	Rate of change of school-age population Primary school enrollment ratio (gross and net) Secondary school enrollment ratio (gross and net) Adult literacy rate	Children reaching grade 5 of primary education School life expectancy Difference between male and female school enrollment ratios Women per hundred men in the labour force	GDP spent on education
Chapter 6: Protecting and promoting human health		Basic sanitation: Percent of population with adequate excreta disposal facilities Access to safe drinking water Life expectancy at birth Adequate birth weight Infant mortality rate Maternal mortality rate Nutritional status of children	Immunization against infectious childhood diseases Contraceptive prevalence Proportion of potentially hazardous chemicals monitored in food National health expenditure devoted to local health care Total national health expenditure related to GNP

Chapter 7: Promoting sustainable human settlement development	Rate of growth of urban population Per capita consumption of fossil fuel by motor vehicle-transport Human and economic loss due to natural disasters	Percent of population in urban areas Area and population of urban formal and informal settlements Floor area per person House price to income ratio	Infrastructure expenditure per capita
	Category: Economic		
Chapter 2: International cooperation to accelerate sustainable development in countries and related domestic policies	GDP per capita Net investment share in GDP Sum of exports and imports as a percent of GDP	Environmentally adjusted Net Domestic Product Share of manufactured goods in total merchandise exports	
Chapter 4: Changing consumption patterns	Annual energy consumption Share of natural-resource intensive industries in manufacturing value-added	Proven mineral reserves Proven fossil fuel energy reserves Lifetime of proven energy reserves Intensity of material use Share of manufacturing value-added in GDP Share of consumption of renewable energy resources	
Chapter 33: Financial resources and mechanisms	Net resources transfer/GNP Total ODA given or received as a percentage of GNP	Debt/GNP Debt service/export	Environmental protection expenditures as a percent of GDP Amount of new or additional funding for sustainable development
Chapter 34: Transfer of environmentally sound technology, cooperation and capacity-building	Capital goods imports Foreign direct investments	Share of environmentally sound capital goods imports	Technical cooperation grants

(continued)

TABLE 3. *Continued*

	Category: Environmental		
Chapter 18: Protection of the quality and supply of freshwater resources	Annual withdrawals of ground and surface water Domestic consumption of water per capita	Groundwater reserves Concentration of faecal coliform in freshwater Biochemical oxygen demand in water bodies	Waste-water treatment coverage Density of hydrological networks
Chapter 17: Protection of the oceans, all kinds of seas and coastal areas	Population growth in coastal areas Discharges of oil into coastal waters Releases of nitrogen and phosphorus to coastal waters	Maximum sustained yield for fisheries Algae index	
Chapter 10: Integrated approach to the planning and management of land resources	Land use change	Changes in land condition	Decentralized local-level natural resource management
Chapter 12: Managing fragile ecosystems: combating desertification and drought	Population living below poverty line in dryland areas	National monthly rainfall index Satellite derived vegetation index Land affected by desertification	
Chapter 13: Managing fragile ecosystems: sustainable mountain development	Population change in mountain areas	Sustainable use of natural resources in mountain areas Welfare of mountain populations	
Chapter 14: Promoting sustainable agriculture and rural development	Use of agricultural pesticides Use of fertilizers Irrigation percent of arable land Energy use in agriculture	Arable land per capita Area affected by salinization and waterlogging	Agricultural education

Chapter 11: Combating deforestation	Wood harvesting intensity	Forest area change	Managed forest area ratio Protected forest area as a percent of total forest area
Chapter 15: Conservation of biological diversity		Threatened species as a percent of total native species	Protected area as a percent of total area
Chapter 16: Environmentally sound management of biotechnology			R & D expenditure for biotechnology Existence of national biosafety regulations or guidelines
Chapter 9: Protection of the atmosphere	Emissions of greenhouse gasses Emissions of sulphur oxides Emissions on nitrogen oxides Consumption of ozone depleting substances	Ambient concentrations of pollutants in urban areas	Expenditure on air pollution abatement
Chapter 21: Environmentally sound management of solid wastes and sewage-related issues	Generation of industrial and municipal solid waste Household waste disposed per capita		Expenditure on waste management Waste recycling and reuse Municipal waste disposal
Chapter 19: Environmentally sound management of toxic chemicals		Chemically induced acute poisonings	Number of chemicals banned or severely restricted
Chapter 20: Environmentally sound management of hazardous wastes	Generation of hazardous wastes Imports and exports of hazardous wastes	Area of land contaminated by hazardous wastes	Expenditure on hazardous waste treatment

(continued)

TABLE 3. *Continued*

	Category: Environmental (cont.)		
Chapter 22: Safe and environmentally sound management of radioactive wastes	Generation of radioactive wastes		
	Category: Institutional		
Chapter 8: Integrating environment and development in decision-making			Sustainable development strategies Programme of integrated environmental and economic accounting Mandated Environmental Impact Assessment National councils for sustainable development
Chapter 35: Science for sustainable development		Potential scientists and engineers per million population	Scientists and engineers engaged in R & D per million population Expenditure on R & D as a percent of GDP
Chapter 37: National mechanisms and international cooperation for capacity-building in developing countries			
Chapter 38: International institutional arrangements			

Chapter 39: International legal instruments and mechanisms			Ratification of global agreements Implementation of ratified global agreements
Chapter 40: Information for decision-making		Main telephone lines per 100 inhabitants Access to information	Programmes for national environmental statistics
Chapter 23-32: Strengthening the role of major groups			Representation of major groups in national councils for sustainable development Representatives of ethnic minorities and indigenous people in national councils for sustainable development Contribution of NGOs to sustainable development

Source: United Nations Commission on Sustainable Development, 1996.

and sectoral policies for which a core set of indicators has been developed (Table 4). The OECD has done pioneering work on urban indicators to help national policymakers to monitor urban policies. More recently, OECD urban indicators have been developed as part of the OECD set of environmental indicators to assess the state of the environment and environmental performance.

The OECD has developed a general indicator framework known as Pressure-State-Response (PSR) approach, to help integrate environmental considerations into national decision-making. This approach is based on the assumption that one should distinguish among *pressure indicators*, which monitor the cause of environmental stress; *state indicators,* which describe the state of the environment, and *response indicators*, which measure how effectively society is responding to these problems. Most national and local initiatives aimed at developing urban indicators have followed the OECD PSR framework.

The European Environment Agency (1995) has developed this framework further in order to report on the state of Europe's environment. At the center of the EEA analytical framework are *environmental problems* that can be monitored by focusing on the state of the environment, the causes of environmental stress, and the human activities that generate them. Actions can be taken at different points in the chain to clean up, control, or prevent environmental problems. In this approach, the pressures are the uses of natural resources and the emissions and produced waste—the agents and means by which human activities generate environmental stress—rather than the activities themselves. Indeed the ways in which human activities interact with environmental processes are not always obvious. The EEA approach intentionally distinguishes between "activities" and the "pressures" they generate, to emphasize that human activities per se are not the cause of environmental stress, but rather their size or the way they are carried out. In applying this approach to urban areas, the EEA identifies 55 indicators classified under the three major categories: the patterns of urban development, the flows of natural resources, and the quality of the urban environment (Table 5).

The World Health Organization has developed specific urban health indicators as part of its Healthy City Project, which began in 1986 to test and improve WHO strategy defined as Health for All (HFA) at the local level. According to HFA, five principles should guide health policies: (1) equity, (2) empowerment, (3) participation, (4) cooperation, and (5) local primary health care. The Healthy Cities Project aims to integrate health policy with urban policy, overcoming traditional administrative and professional boundaries that separate the health of individuals from the health of the environment and both from the health of the community. A set of 53 indicators covering health, health services, environment, population, and socioeconomics has been developed and tested in 47 cities. (Table 6).

While international and regional agencies are interested in monitoring the progress of urban areas towards global and regional goals set in international plans of actions, local agencies select urban indicators in an effort to inform local planning and community response to environmental problems. Recently many cities in Europe and North America have developed environmental performance indicators to help them report on the state of the environment (Alberti and Bettini 1996; McLaren 1996). In Seattle, a civic forum has selected a set of 20 sustainability indicators from an initial list of more than 200 indicators (Table 7) (Sustainable Seattle 1993, 1995). The initiative aimed at highlighting what is happening in the urban system and the direction in which critical urban issues are evolving (see article in this issue).

More recently several communities have been developing indicators to help design local action plans, following the general principles set out in Agenda 21. As part of the UK's Local Agenda 21 Initiative, ten local authorities in the United Kingdom have developed sets of indicators (LGMB 1995). In Leicester, for example, a set of 14 indicators—ranging from environmental quality, social equity, economic opportunity, and health—have been selected from a list of 101 possible indicators covering 13 themes (Table 8) (Leicester City Council 1995). At the local level, increasing attention is now being placed on setting sustainability benchmarks. Benchmarks are targets set for reviewing the effectiveness of specific policies in relation to selected indicators. Following Oregon's Benchmark Initiative, a few communities have adopted a bottom-up approach to develop benchmarks of metropolitan performance (HUD 1996). Three U.S. cities—Chattanooga, Noblesville, and Pittsburgh—are now developing community-based indicators of urban quality of life and sustainable development in an attempt to integrate local and regional perspectives.

Local Versus Global Indicators

The sets of indicators described above reflect diverse degrees of importance that the different organizations and programs place on various aspects of sustainability. The OECD and UNCSD sets of indicators aim at monitoring national performance. However, while the OECD core set of environmental indicators focuses on environmental performance, UNCSD indicators aim at monitoring sustainable development. Therefore, the UNCSD working list considers a broader set of indicators including social, economic, environmental, and institutional indicators. Similarly, UNCHS, the EEA and WHO who have developed sets of indicators to monitor trends at the urban scale 5 place different degrees of emphasis on the socioeconomic and environmental concern. While UNCHS set of indicators emphasizes the socioeconomic and institutional dimension of urban sustainability, EEA and WHO indicators focus primarily on the environment and human health. It is clear

TABLE 4. OECD Indicators

	Pressure	State	Response
Issues	Indicators of environmental pressures	Indicators of environmental conditions	Indicators of societal responses
1. Climate change	Emissions of CO_2	Atmospheric concentrations of greenhouse gases Global mean temperature	Energy intensity
2. Stratospheric ozone depletion	Apparent consumption of CFCs	Atmospheric concentration of CFCs	
3. Eutrophication	Apparent consumption of fertilizers, measured in N,P	BOD, DO, N and P in selected rivers	% of population connected to waste water treatement plants
4. Acidification	Emissions of SOx and NOx	Concentrations in acid precipitations (pH, SO_4, NO_3)	Expenditure for air pollution abatement
5. Toxic contamination	Generation of hazardous waste	Concentration of lead, cadmium, chromium, copper in selected rivers	Market share of unleaded petrol

6. Urban environmental quality		Concentrations of SO_2, NO_2, particulates in selected cities	
7. and 8. Biological diversity and landscape	Land use changes	Threatened or extinct species as % of known species	Protected areas as % of total area
9. Waste	Generation of municipal, industrial, nuclear, hazardous waste	not applicable	Expenditure on waste collection and treatement Waste recycling rates (paper and glass)
10. Water resources	Intensity of use of water resources		
11. Forest resources		Area, volume and distribution of forests	
12. Fish resources	Fish catches		
13. Soil degradation (desertification and erosion)	Land use changes		
14. General indicators, not attributable to specific issues	Population growth and density GDP growth Industrial and agric. production Energy supply and structure Road traffic and vehicle stock	not applicable	Pollution abatement and control expenditure Public opinion on the enviornment

Source: OECD, 1993.

TABLE 5. EEA Indicators

	A. Indicators of urban patterns	
1. Urban population	a) Population	• number of inhabitants in city (1)* in conurbation (2)
	b) Population density	• population per km^2 (3) • area by density classes (4)
2. Urban land-cover	a) Total area	• area in km^2 (5)
	b) Total built-up area	• area in km^2 (6) • by landuse (7)
	c) Open area	• area in km^2 (8) • % green areas (9) • % water (10)
	d) Transportation network	• motorway length (km) (11) • railway length (km) (12) • % of total urban area (13)
3. Derelict areas	Total area	• area in km^2 (14) • % of total urban area (15)
4. Urban renewal areas	Total area	• area in km^2 (16) • % of total urban area (17)
5. Urban mobility	a) Modal split	• number (18) and average length (19) of trips in km per inhabitant per mode of transportation per day
	b) Commuting patterns	• number of commuters into and out of conurbation (20) • as % of the urban population (21)
	c) Traffic volumes	• total (22) and inflow/outflow (23) in vehicle-kms • (24) number of vehicles on main routes
	B. Indicators of urban flows	
6. Water	a) Water consumption	• consumption per inhabitant in litres per day (25) • % of groundwater resources in total water supply (26)
	b) Wastewater	• % of dwellings connected to a sewage system (27) • number (28) and capacity (29) of treatment plants by type of treatment
7. Energy	a) Energy consumption	• electricity use in GWh per year (30) • energy use by fuel type and sector (31)
	b) Energy production plants	• number (32) and type (33) of power and heating plants in the conurbation
8. Materials and products	Transportation of goods	• quantity of goods moved into and out of the city in kg per capita per year (34)
9. Waste	a) Waste production	• amount of solid waste collected in tonnes per inhabitant per year (35) • composition of waste (36)
	b) Recycling	• % of waste recycled per fraction (37)
	c) Waste treatment and disposal	• number of incinerators (38) and volume (39) incinerated • number of landfills (40) and volume (41) received by waste type

(continued)

TABLE 5. *Continued*

	C. Indicators of urban environmental quality	
10. Quality of water	a) Drinking water	• number days per year that the WHO drinking water standards are exceeded (42)
	b) Surface water	• O_2 concentration of urban surface water in mg per litre (43) • number of days pH is > 9 or < 6 (44)
11. Quality of air	a) Long term; SO_2 + TSP	• annual mean concentrations (45)
	b) Short-term concentration: O_3, SO_2, TSP	• exceedances of AQGs: O_3 (46) SO_2 (47), TSP (48)
12. Acoustic quality	Exposure to noise (inhabitant per time period)	• exposure to noise above 65 dB (49) and above 75 dB (50)
13. Traffic safety	Fatalities and casualties from traffic accidents	• number of people killed (51) and injured (52) in traffic accidents per 10,000 inhabitants
14. Housing quality	Average floor area per person	• m^2 per person (53)
15. Accessibility of green space	Proximity to urban green areas	• percentage of people within 15 minutes walking distance of urban green areas (54)
16. Quality of urban wildlife	Number of bird species	• number of bird species (55)

* Indicator number in parentheses
Source: EEA 1995.

however that these sets of indicators reflect specific areas of concerns for which these organizations have specific mandates for monitoring. Thus it should not be surprising if emerging sets of urban indicators at the international level are still too compartmentalized and fragmented to provide a synthetic view of urban sustainability.

On the other hand, some of the most innovative experiences emerging at the local scale, such as Sustainable Seattle and Leicester, highlight that sustainability, at the community level, is perceived as a holistic concept and not simply the sum of the environment, economy, society, and culture. The links among these components are established by the people and expressed in terms of people needs and aspirations. Both in Seattle and in Leicester the public played a crucial role in selecting indicators. These experiences show that the importance attached to the various problem areas relevant for sustainability varies among the various communities.

In summary, three elements seem most relevant in comparing local and global frameworks. A first element is the broad coverage of indicator themes. Both international and local sets of indicators include a very broad definition of urban quality and performance. Whether at the international

TABLE 6. WHO Healthy Cities Indicators*

Provisional (April 1994)

A. Health Indicators
- Mortality: all causes
- Cause of death
- Low birth weight

B. Health Service Indicators
- Inventories of self-help organizations
- Support programs for self-help organizations
- Health education programs
- % of six years old children fully immunized
- # of inhabitants per practicing general practitioner
- # of inhabitants per nurse
- % of population covered by health insurance
- % of population having access to an emergency medical service in less than 30 min. by car
- Availability of primary health care services in foreign language
- Health information communication
- # of health questions examined by the city council every year

C. Environmental Indicators
- Atmospheric pollution
  Concentrations of SO_2, NO_x, O_3, CO, Lead, Particulate (annual mean)
  Exceedances of 1 h CO and O_3 AQGs
- Microbiological quality of water supply
- Chemical quality of water supply
- % of water pollutants removed from total sewage produced
- Household waste collection quality index
- Household waste treatment quality index
- Quantity of drinking-water used per inhabitant per day
- Relative surface area of green spaces in the city
- Public access to green spaces
- Derelict industrial sites
- Sport and leisure
- Pedestrian streets
- Cycling in the city
- Public transport
- Public transport network cover
- Living space
- Comfort and hygiene
- Emergency services
- Pollution level indicator as perceived by the population

D. Socio-Economic Indicators
- Living space per inhabitant (m^2)
- % of population in substandard dwelling
- Estimated number of homeless people
- Unemployment rate
- Work absenteeism rate
- % of families below national poverty level
- % of total employment provided by ten most important economic activities
- % of one-person households

(*continued*)

TABLE 6. *Continued*

- % of single parent families
- % of children leaving school after compulsory education
- Illiteracy rate
- % of city budget allocated to health and social actions
- Crime rate
- % of dwellings for elderly people that have emergency call facilities
- Main causes of emergency calls
- % of young children on waiting lists for child care facilities
- Median age of women giving birth for the first time
- Abortion rate in relation to total number of births
- % of people under 18 'under police surveillance'
- % of disabled people in employed compared to total number of disabled people of working age

E. General Information

- Census
- Education
- Professional categories
- Surface area of population unit

* The prosed list of Healthy Cities Indicators are currently being revised.
Source: WHO (1994).

or the local level, the challenge for these programs is to integrate social, economic, and environmental considerations into the same framework. However, local and international agencies have adopted different strategies. While international programs tend to include extremely detailed lists of each category of indicators, local communities are more selective. Their aim is to achieve a very limited list of measures that can detect critical trends at the local scale.

A second element is the different interpretations of sustainability. International sets of indicators focus on specific areas of concerns—environmental, natural resources, health, and poverty issues—where a specific institutional framework exists. In contrast, local communities' indicators tend to place much more emphasis on the social and quality-of-life dimensions. For example, a study by the UK Local Agenda 21 Initiative tested recently the selection of 101 indicators in ten local communities and concluded that indicators are considered useful only when they are "owned" by local communities and when they measure issues of local relevance (LGMB 1995).

A third element is the extent to which the public participates in the process of selecting indicators. In the cases of both Sustainable Seattle and Leicester, the public played a critical role in selecting indicators and assessing their trends. The Local Agenda 21 Initiative in the United Kingdom attaches increasing importance to engaging the public in developing, collecting, and using sustainability indicators. Even more importance is given to public participation in selecting benchmarks. In contrast, participation in international programs is extremely limited.

TABLE 7. Sustainable Seattle Report Card

← *Moving away from sustainability* → *Toward sustainability* – *Neither toward nor away*

	Environment
←	Wild salmon runs through local streams
→	Number of good air quality days per year
–	Percentage of Seattle streets meeting "Pedestrian-Friendly" criteria
	Population and resources
←	Total population of King County
→	Gallons of water consumed per capita in King County
←	Tons of solid waste generated and recycled per capita per year in King County
←	Vehicle miles traveled per capita and gasoline consumption per capita
←	Renewable and nonrenewable energy (in BTUs) consumed per capita
	Economy
→	Percentage of employment concentrated in the top ten employers
–	Hours of paid work at the average wage required to support basic needs
←	Percentage of children living in poverty
←	Housing affordability for median- and low-income households
←	Per capita health expenditures
	Culture and society
←	Percentage of infants born with low birthweight
←	Juvenile crime rate
–	Percent of youth participating in some form of community service
←	Percent of population voting in odd-year (local) primary elections
–	Adult literacy rate
→	Library and community center usage rates
–	Participation in the arts

Source: Sustainable Seattle (1993).

Sustainability indicators

While the frameworks described above contain the elements essential to monitor urban trends, measuring sustainability will require a more sophisticated set of indicators. Indeed, such indicators should not only tell us how much environmental stress human activities generate or how well the environment is responding to such stress. They should also be able to indicate whether environmental systems can absorb such stress in the long term. The question is how to relate traditional measures of urban environmental quality and performance to the state of the natural resource base. I use the four categories proposed by the World Bank (Table 9) and by the World Resources Institute (1995), to identify key areas that need to be explored in linking local and global sets of indicators. These include (1) source indicators, (2) sink indicators, (3) ecological support system indicators, and (4) human impact and welfare indicators.

SOURCE INDICATORS. The sustainability of resource use at the urban scale can be monitored establishing clear linkages between urban trends in consumption of food, energy, materials, and water and the state of natural resources. Source indicators should be able to measure how much certain level of resource use departs from its sustainable use, considering both the state of natural resources and the biological processes that sustain them. In addition, the level of dependence of a city from external resources can be monitored. Composite indices of resource depletion similar to national indices can be calculated at the urban scale by measuring the value of depleted resources relative to the value of urban investment in man-made capital.

Both international and local sets of indicators make explicit reference to sources. UNCHS and the World Bank, for example, refer to land-use change, energy, and consumption per capita, and water consumption per capita. The EEA refers to urban flows of energy, water, and materials. Other organizations such as UNCSD and the OECD have developed source performance indicators at the national rather than the urban level. Sustainable Seattle and Leicester have both included indicators of sources.

SINK INDICATORS. In the urban context, most sink indicators have been developed to evaluate the capacity of local atmosphere, soil, or water bodies to absorb emissions and waste. More complex is the task of selecting urban indicators for sinks relevant at the regional and global scale in order to address issues of global climate change, acidification, eutrophication, and toxification. UNCHS and the World Bank consider a few of the most obvious global sink indicators, such as CO_2 and CFCs emissions. Other international organizations propose sink indicators only at the national level. While it would be quite arbitrary to establish urban thresholds for global sinks, the rates of emissions of global pollutants such as CO_2 or CFCs can be assessed against targets established by national regulations and international conventions.

ECOLOGICAL SUPPORT SYSTEM INDICATORS. Sustainability implies that essential life-support systems be maintained over time without degrading their quality. These systems provide essential services, ranging from nutrient recycling, to water purification, to the maintenance of biodiversity. At the local scale, urban indicators can be easily identified to monitor change in the state of ecosystems, protected areas, and biodiversity. Most current programs include urban indicators to measure the loss of natural habitats at the local scale. Both UNCHS and the World Bank, as well as the EEA, include measures such as the percentage of agricultural land or forest lost to urbanization. These measures, however, generally do not refer to specific ecosystem areas, nor do they show how cities and their specific activity sectors contribute to the degration of global life-support systems.

HUMAN IMPACT AND WELFARE INDICATORS. Unlike the previous categories of indicators, human impact and welfare indicators are well-developed in these programs. Urban environmental problems have long been associ-

TABLE 8. Key Monitoring Aims Chosen for an Ideal Set of Core Sustainable Development Indicators in Leicester and the Resulting Indicators after a Data Availability Appraisal Exercise

Specialist Working Group Topic	Key Monitoring Aim	Resulting Core Indicators
Built environment	Measures of change in: • the sustainable use of materials and land; • the quality of the built environment; • the extent to which the land use pattern affects accessibility and the need to travel.	• Perceived improvement in the city centre • Satisfaction with the neighbourhood
Economy and work	Measures of change in: • the provision of employment opportunities; • the fulfilment of people's needs and aspirations through employment; • the environmental impacts of employment opportunities.	• Unemployment rate • High and low levels of earned income
Energy	Measures of change in the environmental impacts of: • local energy use; • local energy production.	• Energy use
Landscape and ecology	Measures of change in: • the quantity of green open space; • the quality of green open space; • the accessibility of green open space.	• Good quality wildlife habitat lost to development
Pollution	Measures of the impacts of all pollutants which may adversely affect either people's health or the environment.	• Air quality • River and canal pollution
Social environment	Measures of change in: • the provision of educational opportunities; • health protection; • freedom from crime; • cultural and leisure opportunities; • strength of community.	• Levels of asthma • Homelessless • Violent crime • Educational attainment at GCSE level
Transport	Measures of change in the social and environmental impacts of travel.	• Mode of transport to work
Waste	Measures of change in the environmental impacts of: • non-renewable resource use (non-energy); • waste disposal.	• Domestic refuse collected

Source: Leicester City Council 1995.

TABLE 9. Global Environmental Indicators

Issues	Pressure	State	Response
I. Source indicators			
Agriculture	Value Added/Gross Output	Cropland as % of Wealth	Rural/Urban Terms of Trade
Forests	Land Use Change	Area, Volume, Distribution	Input/Out Ratio
Marine Resources	Contaminants, Demand	Stock of Marine Species	% Coverage of int'l Protocol/Conventions
Water	Intensity of Use	Accessibility to Population	Water Efficiency Measures
Subsoil Assets	Extraction Rate	Subsoil Assets as % of Wealth	Material Balances/NNP
II. Sink Indicators			
Climate change			
—Greenhouse gases	Emissions of CO_2	Atmosph. Concentr. of GHGs	Energy Efficiency of NNP
—Stratospheric ozone	Consumption of CFCs	Atmosph. Concentr. of CFCs	% Coverage of int'l Protocol/Conventions
Acidification	Emissions of SOx, NOx	Concentr. of pH, SOx, NOx in Precipitation	Expenditures on Pollution Abatement
Eutrophication	Use of Phosphates (P), Nitrates (N)	BOD, P, N in Rivers	% Pop. w/Waste treatment
Toxification	Generation of Hazardous Waste/Load	Concentr. of Lead, Cadmium, etc., in Rivers	% Petrol Unleaded
III. Life-Support Indicators			
Biodiversity	Land Use Change	Habitat/NR	Protected Areas as % Threatened
Oceans	Threatened, Extinct Species % of Total		
Special Lands	Wetlands Lost		
IV. Human Impact Indicators			
Health	Burden of Disease	Life Expectancy at Birth	% NNP spent on Health Access to Safe Water
Food Security			
Housing Urban	Population Density		% NNP Spent on Housing
Waste	Generation of Waste	Accumulation to date	Expenditure on Collection, Treatment and Recycling
Natural Disasater			

ated with local problems, particularly public health and quality of life. Indeed, cities are where people live and where environmental problems affect the population. Most of the indicators developed by the WHO Healthy City program fall into this category. Just as important as the public health indicators are the social and economic indicators developed by WHO, UNCHS, and the World Bank. The local communities are, however, the most innovative in developing urban indicators that go beyond the environmental dimension. The lists of indicators selected by Sustainable Seattle and by Leicester show that sustainability in an urban context depends primarily on what people in the urban community value and perceive as sustainable. The question is how to make the global and local perspectives consistent.

3. Selecting Urban Indicators

In principle, effective monitoring of urban environmental quality and performance should provide planners with the information they require to design sustainable land-use plans, efficient transportation systems, and greater access to services and infrastructures for urban dwellers, to mention a few examples. This information should also improve the way urban dwellers live in and use cities. Indicators work as feedback mechanisms. They succeed when the users modify their behavior in light of the new information available.

Most urban indicator programs refer to four key characteristics of successful indicators:

1. Policy relevance.
2. Scientifically founded.
3. Readily implemented.
4. Usable for decision-making.

To identify key strategies for each of these aspects, we need to answer the following questions: What information do we need in order to identify and prioritize the most relevant problems? How do we ensure that the information is reliable and scientifically sound? Who should be involved in the process of selecting indicators? And, what mechanisms need to be in place to ensure that the information will feed back into the decision-making process?

Building a Shared Vision

The choice of indicators depends on the purpose for monitoring. Local planners are interested in measures of urban environmental stress such as the local concentrations of air pollution, the noise level at a given location, and other relevant environmental variables that can be assessed in relation to specific urban policies and strategies. National policymakers, on the other hand, are more interested in measures that are comparable across a variety of city sizes, geographic conditions, and economic structures. Their lists of indicators will include more general variables. Furthermore, depending on their purpose, a given agent or organization will place varying degrees of importance on the social, economic, and physical dimensions of the urban environment. There are also many purposes for monitoring urban sustainability in both the private and public sectors.

One starting point to achieve consensus on a set of key indicators will be to develop a shared vision of sustainability. The concept of sustainability has changed the traditional boudaries of urban interests and pointed out that local and national organizations share important goals. Cities need to recognize their responsibility for the global commons when making their trade-offs. National policymakers, on the other hand, need to recognize the urban dimension of national sectoral policies. Furthermore, all parties need to recognize the common benefits of meeting everybody's needs. Selecting a set of widely accepted urban sustainability indicators will require that those involved in deciding what urban sustainability entails and what key trends they need to monitor work together to build this vision. We need to achieve a vast consensus both at the local and international levels on a operational definition of urban sustainability before local and international communities can agree on what variables to select and how to measure them.

Integrating Science and Policy

There is wide agreement that indicators must be both scientifically sound and relevant to policy. UNCHS stresses that indicators should be policy-oriented, guiding policy during the three crucial stages of developing a strategy, monitoring implementation, and evaluating its success. UNCHS methodology aims to define indicators that can support a very broad range of policy areas and geographic scales. UNCHS indicators also address a broad range of actors who may incorporate such information in their normal mode of operation: residents or consumers, city managers, national government agencies, commercial and business organizations, NGOs and CBOs, and external support agencies.

The OECD approach uses three selection criteria: political relevance, scientific soundness, and measurability. The political relevance of an indicator refers both to its usefulness and its pertinence to the issue under consideration. Indicators are expected to meet the following requirements:

- provide a representative picture of environmental conditions, pressure on the environment, or society's response;
- be simple, easy to interpret, and able to show trends over time;
- be responsive to change in the environment and related to human activities;

- provide a basis for international comparisons; and
- have a target or threshold against which to compare environmental quality and performance.

The scientific soundness of indicators can be measured by the following criteria:

- theoretically well-founded in technical and scientific terms;
- based on international standards and international consensus about its validity; and
- capable of linkage with economic models, forecasting, and information systems.

The measurability of indicators requires that data be:

- readily available at a reasonable cost/benefit ratio;
- adequately documented and of known quality; and
- updated at regular intervals.

While implementing these criteria may appear a straightforward task, there are sharp disagreements among scientists and policymakers concerning the best measures and methods to measure sustainability. Designing indicators that reflect these criteria require the ability to handle disagreements among these groups and to balance scientific, policy, and feasibility considerations in the process of identifying and applying indicators.

Improving Data Quality and Availability

One major obstacle in implementing indicators of sustainability is the lack of urban environmental information. The problems of data quality and comparability are amplified at the urban level. Most environmental data available at the urban scale are those of local concern or for which national laws require the municipalities monitor trends. At the same time, most environmental data of national and global relevance—such as energy consumption—are not available at the urban level. While monitoring activities at the urban level are well-established on atmospheric concentrations of certain pollutants where environmental standards are implemented, they are much less developed on other environmental aspects such as acoustic quality and green areas. Furthermore, the information to monitor the environmental pressures that cities exert on the global environment is not collected at the urban level. On the basis of an assessment of 72 European cities, the EEA (1995) pointed out that the information on energy consumption disaggregated by fuels, activities, or district were not available in the majority of the city. Instead it is possible to obtain data on specific services delivered at the municipal level such as electricity consumption, water use, and waste production. Other data generally available at the municipal level are not easily comparable across cities since they use different classification systems and measurement methods. These include land use, mobility, and infrastructure. Such issues of data availability and comparability have imposed important constraints on the lists of indicators that can be selected at the local level.

Establishing Feedback Mechanisms

Indicator programs aim at improving the signals that are given both to citizens and decision-makers on the sustainability of urban patterns and trends. Thus far, the attention of these programs has been on selecting indicators that best respond to monitoring needs. Despite the progress in developing urban indicators, little is known about how best to design feedback mechanisms to ensure that the signals work and have an impact on urban decision-making. There is significant evidence from the social indicators movement that consensus on the character and design of these measures plays a crucial role (Innes 1990; Alberti and Parker 1991). Drawing upon the controversial history of social and quality-of-life indicators, we can conclude that sustainability indicators will not affect urban policymaking unless there is consensus on how sustainability problems are defined and prioritized. Therefore, strategies to achieve consensus in selecting these measures are crucial to their effective use. Furthermore, the data must be based on the best available scientific knowledge and information. Attention needs to be given to recalibrating indicators to new scientific knowledge and policy goals.

4. Conclusions

The design and management of cities are critical to global sustainability. A key question is how to provide cities the essential information to help them maintain Earth's natural capital in the long term. What set of indicators can help policymakers and the public obtain the right signals and chart city efforts to achieve sustainability? In this article I have suggested that measures of urban sustainability need to provide clear signals as to how urban patterns are affecting the environment and the natural resource base. Urban planners and managers need to recognize that their decisions affect ecological systems far beyond the city boundaries or the region. Only then will we be able to design tools to monitor urban sustainability and build sustainable cities.

The global and local perspectives are both necessary to develop a common framework to help public agencies determine information needs and establish the proper levels of monitoring. International organizations concerned with urban problems have suggested the importance of harmonizing urban indicators and urban data collection worldwide. Local communities, on the other hand, have clearly indicated sets of indicators that reflects their priorities. The challenge for international programs is to provide a framework that can help local communities select community-based sustainability measures and facilitate their participation in selecting a world-wide set of urban indicators.

Several practical steps should be considered:

1. Create a public forum involving all groups in the community and facilitate their participation to help identify key issues and select indicators.
2. Create expert panels and opportunities for policymakers to interact with them in setting targets and criteria for evaluating indicators.
3. Identify data needs and specific mechanisms for their systematic collection.
4. Explore opportunities for linkages among urban policy areas and between urban-monitoring activities and policymaking.
5. Establish mechanisms to evaluate indicators and recalibrate them towards new policy goals.

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