Global J. Environ. Sci. Manage., 1(2): 159-188, Spring 2015
ISSN 2383 - 3572

Review Paper

Ecological approaches in planning for sustainable cities A review of the literature

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Received 22 October 2014; revised 2 December 2014; accepted 14 December 2014; available online 1 March 2015

ABSTRACT: Rapid urbanization has brought environmentally, socially, and economically great challenges to cities and societies. To build a sustainable city, these challenges need to be faced efficiently and successfully. This paper focuses on the environmental issues and investigates the ecological approaches for planning sustainable cities through a comprehensive review of the relevant literature. The review focuses on several differing aspects of sustainable city formation. The paper provides insights on the interaction between the natural environment and human activities by identifying environmental effects resulting from this interaction; provides an introduction to the concept of sustainable urban development by underlining the important role of ecological planning in achieving sustainable cities; introduces the notion of urban ecosystems by establishing principles for the management of their sustainability; describes urban ecosystem sustainability assessment by introducing a review of current assessment methods, and; offers an outline of indexing urban environmental sustainability. The paper concludes with a summary of the findings.

Keywords: *Sustainable urban development, Sustainable city, Urban ecosystems, Sustainability assessment, Environmental indicators*

INTRODUCTION

The quality of natural resources have been exposed to significant degradation from increased urban populations combined with the sprawl of settlements, development of transportation networks and industrial activities. Therefore, the concept of sustainability has been pushed to the forefront of policymaking and politics as the world wakes up to the impacts of climate change and the effects of the rapid urbanisation and modern urban lifestyles (Yigitcanlar and Teriman, 2014). Mitigating global climate change and neutralising the impacts of fossil fuel-based energy policy on the environment have emerged as the biggest challenges for the planet, threatening both built and natural systems with long-term consequences. However, the threats are not limited to the impacts of global climate change (Wilson and Piper, 2010) and unsustainable energy system (Kim *et al.*, 2012) only. For instance, impacts of rapid urbanisation, socioeconomic crises, governance hiccups are just to name a few (Owens and Cowell, 2011; Rana, 2011). Along with aforementioned challenges successfully coping with the enormous transformations that cities, societies and the environment have been going through during the last few decades, and their consequential impacts being faced today, call for a more effective and resilient planning and development perspective (Yigitcanlar and Lee, 2014). Scholars across the globe see 'sustainable urban development' as a contemporary paradigm to address these challenges, and provide an opportunity to form new mechanisms for building a desirable urban future (Runhaar *et al.*, 2009).

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Sustainable urban development of cities in the world is perceived as improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden, and thus forming the sustainable city (Flint and Raco, 2012). In other words, it is seen as a development and growth pattern that requires harmony with life-support environments, ranging from local and regional to global ecosystems (see Geertman *et al.,* 2013).

Due to the critical importance of achieving sustainable urban development for maintaining the long-term wellbeing of the environment and societies (Yigitcanlar, 2010a; Ahmadi and Toghyani, 2011; Blackwood *et al.,* 2014), this paper focuses on the ecological approaches for planning sustainable cities to provide insights for researchers and practitioners. The ecosystem approach is chosen for investigating ways to achieve sustainable outcomes as much of the scholarly discussion and literature point out the potential of the approach and emphasise the need to work across all manner of human boundaries at different geographic scales (e.g., Kay *et al.,* 1999; Kissinger and Rees, 2010; Yigitcanlar, 2010b; Reyers *et al.,* 2013; Goonetilleke *et al.,* 2014). As the methodological approach for the investigation of the topic, the paper undertakes a thorough review of the literature and best practice cases from all across the globe.

LITERATURE REVIEW

Human and the Environment Interactions

Since the mid-20th century, globalisation and the growth of human population have been threatening the sustainability of resources by changing the structure and functioning of the environment, where it is a process of international integration arising from the interchange of world views, products, ideas and other aspects of culture (Kissinger and Rees, 2010; Martens and Raza, 2010) Activities of rapidly increasing world population- e.g., consuming more and more natural resources, damaging the climate, generating more waste than ever- have pushed the limits of the carrying capacity of the Earth, and rapid urbanisation along with changing needs and lifestyle expectations of people resulted in drastic deterioration of the natural environment (Mahbub *et al.,* 2011). Moreover, globalisation, rapid urbanisation, development of industrialisation and modern transportation systems, increased consumerism and overproduction has affected the natural environment in several ways (Fig. 1). In other words, as stated by Vitousek *et al.* (2008), "it is clear that we control much of Earth, and our activities affect the rest. In a very real sense, the world is in our hands and how we handle it will determine its composition and dynamics, and our fate".

Human activities have complex and destructive impacts on soil quality and productivity. Population pressure increases the demand for land use by encouraging deforestation. Destruction of vegetation cover through urbanisation and agricultural activities results in the loss of soil fertility and fragmentation of landscape. These activities also disrupt the natural gas and nutrient cycling in ecosystems. Altered soil structure causes poor irrigation and drainage systems. Soil erosion is another critical environmental issue resulting from soil compaction. Furthermore, the use of chemicals in agriculture, and hazardous waste generated by construction and industrial activities threaten human health and the environment (Cropper and Griffiths, 1994; Ojima *et al.,* 1994; Dorsey, 2003; Pauleit *et al.,* 2005; Jenks and Jones, 2010).

Urban development and population pressure are associated with degraded water quality and aquatic systems (Teriman *et al.,* 2009). The domestic, industrial and commercial discharges from heavily populated urban areas to natural water bodies cause the main type of pollution. Increased impervious surfaces resulting from urbanisation alters the water cycle by decreasing the infiltration of stormwater and increasing surface runoff. Even more dramatically, these surfaces contribute to increased urban flood events. Furthermore, the urban heat island effect, which is a result of impervious surfaces, leads to increased temperatures that are linked to impaired water quality (Barnes *et al.,* 2005; Burton *et al.,* 2013).

Air pollution is another serious environmental problem caused by mainly energy production and use, vehicular traffic and industrial activities. Nitrogen oxides, sulphur oxides, carbon oxides, volatile organic compounds and suspended particulate matter are the main air pollutants that affect human health by causing pulmonary diseases, heart disorders, lung cancer, headache, fatigue, increased mortality and neurobehavioral problems (Mage *et al.,* 1996; Schwela *et al.,* 1997). Furthermore, allergies, asthma, respiratory infections, skin, nose or throat irritations are associated with indoor air pollution in residential and other non-industrial environments (Berglund *et al.,* 1991; Varol *et al.,* 2011).

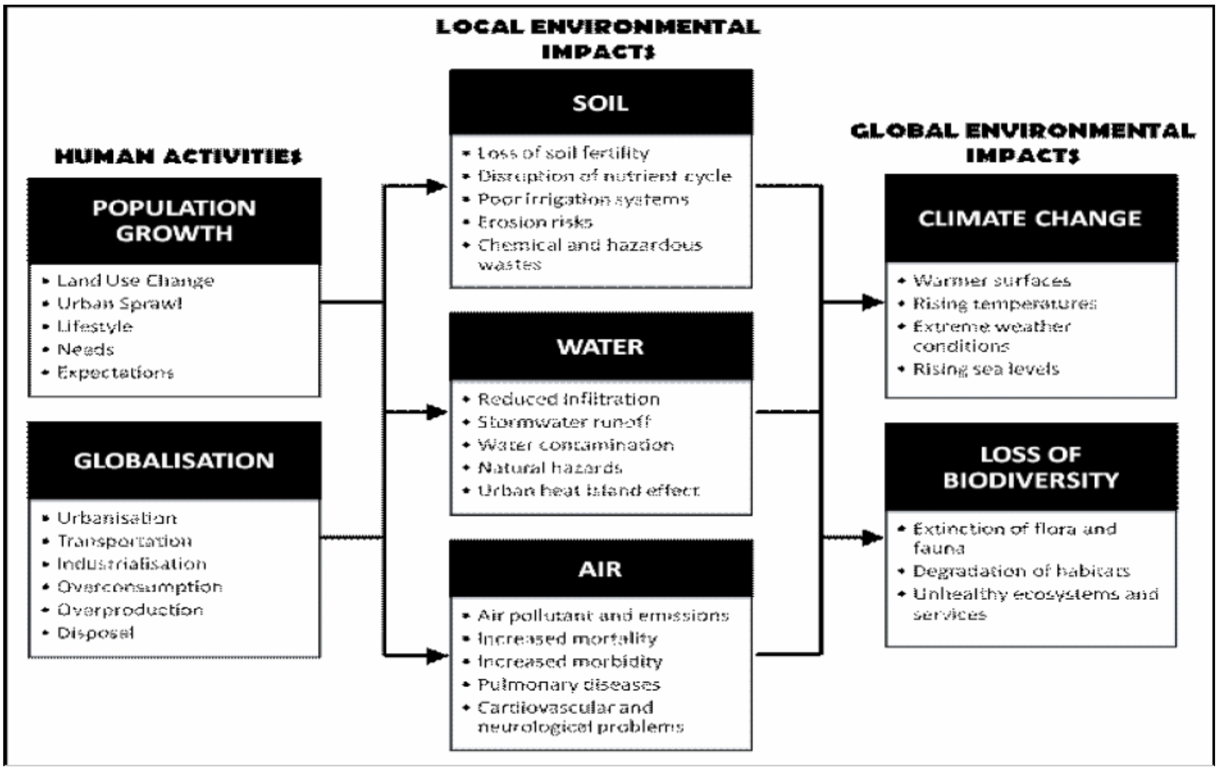

Fig. 1: Impacts of human activities on natural systems

These local environmental impacts mentioned above contribute to two environmental issues, which have global significance: climate change and loss of biodiversity. Due to the increase of impervious surfaces and solar radiation, emissions of greenhouse gases and aerosols alter the energy balance of the Earth's climate system by causing a phenomenon known as global warming (IPCC, 2007). The main impacts of climate change are: (i) Warmer surfaces that lead to higher water temperatures, droughts, food shortages, increased water loss and irrigation demand; (ii) Intense precipitation rates that lead to natural disasters such as floods, soil erosion or landslides; (iii) Rising sea levels due to melting polar ice and glaciers, and; (iv) Human exposure to extreme temperatures and devastating weather events such as storms or hurricanes (Pittock, 2003; Gilman *et al.,* 2010).

Climate change also has a major impact on biodiversity. Cities are frequently located on rivers, hilltops and along the coastlines, and, hence, a large percentage of Earth's biodiversity exist in urban areas (Convery *et al.,* 2008). Unfortunately, the area of urban settlements is growing faster than the amount of people living in these areas. Such rapid urbanisation is intertwined with climate change and both significantly modify the characteristics of biodiversity by altering the quality and quantity of habitats available to flora and fauna. Furthermore, due to climate change, soil and wind erosion are other issues that have a direct effect on species by damaging soil fertility, soil depth and water storage capacity (Pittock, 2003; Parmessan *et al.,* 2013).

In recent years, cities all over the world have started to struggle with the aforementioned local and global environmental issues. Scholars and practitioners from different disciplines have begun to seek sustainable planning and design solutions to overcome these problems. As stated by Birkeland (2008), the goal is the positive development of built environments which refers to "design of cities, buildings, landscapes and infrastructure that generates healthy ecological conditions, increase the life-support services, reverse the impacts of currents systems of development and improve life quality for everyone". This brings us to the main point: the integration of sustainable development into the current urban development policies and practices is fundamental towards achieving sustainable outcomes for cities.

Sustainable Development in the Urban Context

The concept of 'sustainability' emerged in the early 1970s in response for growing concerns about the impact of development practices on the state of the environment. As stated by Paul Hawken in his book 'The Ecology of Commerce: A Declaration of Sustainability' (Hawken, 1993), sustainability is a manifesto for the destructive human activities: "Leave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do". The core objectives of sustainability as defined by the Commonwealth of Australia (1992) are: "(i) Enhance individual and community welfare by following a path of economic development that safeguards the welfare of future generations; (ii) Provide equity within and between generations, and; (iii) Protect biological diversity and maintain ecological processes and life support systems".

The debate on sustainability started with the United Nations (UN) Stockholm Conference on the Human Environment in 1972. In this conference, a declaration was produced emphasising the international concern about environmental protection. The declaration proclaimed that environmental problems have become a growing global concern, and, thus international cooperation among nations, governments and non-governmental organizations is required to deal with this matter. In 1980, the International Union for the Conservation of Nature and Natural Resources prepared the World Conservation Strategy, which was the first attempt to promote the principles of the sustainable use of natural resources. In 1983, the UN established the World Commission on Environment and Development, which was charged with developing a global agenda for the conservation of natural resources. The commission published a report known as the Brundtland Report in 1987 and the term 'sustainable development' was first introduced in this report. The report proposed sustainable development as a global goal to achieve a harmonious balance of the three components of urban development: social welfare, economic development and environmental protection (Smith, 1995; Sum and Hills, 1998; Mörtberg *et al.*, 2013).

In 1992, the UN Conference on Environment and Development, also known as the Rio Earth Summit, was organised. The Rio Conference produced Agenda 21, which provides a comprehensive plan of action for sustainable development. Furthermore, the conference concluded with four major agreements including: (i) The Rio Declaration on Environment and Development which refers to 27 principles of sustainable development; (ii) The convention for the prevention of climate change; (iii) The convention for the conservation of biological diversity, and; (iv) The statement of principles for the sustainable management of forests. In 1996, the UN HABITAT II conference was held in Istanbul. This conference produced a Habitat Agenda, which was signed by 171 countries to show their commitment towards ensuring a better living environment for their citizens. In 1997, the Kyoto Protocol was agreed in the UN Framework Convention on Climate Change. The Kyoto Protocol is an environmental agreement that contains legally binding emission targets for industrialised countries to be achieved (Böhringer and Vogt, 2004). In 2002, the World Summit on Sustainable Development was held in Johannesburg. The summit discussed the global challenges in respect of conservation of natural resources, sustainable consumption and production, eradication of poverty and development of a healthy and productive life. Since then, sustainable development in the urban context- i.e., sustainable urban development- has gained more importance as a fundamental objective for global sustainability (Smith, 1995; Sum and Hills, 1998; Cheng and Hu, 2010).

Sustainable development is a self-contradictory term, or paradox, consisting of two words, that have completely different meanings. Sustainability refers to maintaining the existence of the ecosystem and its services while also providing for human needs, while, in contrast, development refers to any activity that improves the quality of life by depleting natural resources and devastating natural areas (Yigitcanlar, 2009). According to Baker (2007), sustainability is used to describe how an ecosystem can sustain itself over time. The addition of development to sustainability needs to focus on forming a balance between human beings and the natural environment by using resources carefully and transferring them to the next generations.

In the literature, there are many definitions of sustainable development. The most widely definition of sustainable development was developed by the World Commission on Environment and Development

(WCED, 1987) in its report Our Common Future: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. The World Conservation Union (IUCN/UNEP/WWF, 1991) provides another definition of sustainable development: “improving the quality of human life while living within the carrying capacity of supporting ecosystems”. A more comprehensive definition was developed by Jacobs and Munro (1987): “sustainable development seeks to respond to five broad requirements: (i) Integration of conservation and development; (ii) Satisfaction of basic human needs; (iii) Achievement of equity and social justice; (iv) Provision of social self-determination and cultural diversity, and; (iv) Maintenance of ecological integrity”.

Environmental quality, economic prosperity and social equity are the three pillars of sustainable development and their interaction can be explained as follows; environmental quality is the necessary basis for sustainable development by using economic prosperity as a tool towards achieving the target of providing a sufficient life for present and future generations (European Economic Area, 2006; Dijken *et al.,* 2008). As a necessary basis for sustainable development, the environmental dimension refers to securing the living and physical environment through the sustainable use of natural resources. As a tool in achieving sustainable development, the economic dimension refers to the effective distribution of limited resources, goods and services in order to satisfy the needs of all people living now as well as all people of future generations. As the target of sustainable development, the social dimension refers to improving the quality of life by achieving social equity which targets allocating resources equitably and allowing all members of the society to take advantage of public services such as education, health and transport (Torjman and Minns, 2001; European Economic Area, 2006; Tweed and Sutherland, 2007; Kamruzzaman *et al.,* 2014). To sum up, it becomes necessary to provide the sustainable balance of human activities in the natural environment by applying sustainable development principles, which can be summarised as follows:

Sustainable land use and urban design: Sustainable city refers to a vision of an ideal urban structure formed by sustainable land use and urban design principles. Compact urban design with mixed land use: (i) Improve the quality of life by providing social interactions and easier access to a wide range of services; (ii) Minimise energy consumption through green building design technologies; (iii) Reduce greenhouse gas emissions by providing less auto-dependent development, and; (iv) Ease the pressure on environmentally sensitive areas by preventing urban sprawl as well as restoring park and greenway systems (Williams *et al.,* 2000; Coplak and Raksanyi, 2003; Jabareen, 2006; Wheeler, 2013).

Sustainable transportation: The form of current cities indicates that transportation systems are the determinant of the development of city form. Sustainable Transportation refers to transportation services that respect the carrying capacity of the Earth’s systems by promoting energy-efficient and environmentally friendly transport options, such as: (i) Providing and maintaining bike paths and bicycle lanes; (ii) Improving pedestrian ways and their connectivity; (iii) Promoting accessibility of public transport, and; (iv) Reducing traffic road usage demand through implementing congestion pricing, road use or parking charges, vehicle taxes (Drumheller *et al.,* 2001; Coplak and Raksanyi, 2003; Jabareen, 2006; AASHTO, 2010; Wheeler, 2013).

Environmental protection and restoration: Urban biodiversity is an important component of the city. One of the principles of sustainable development is to protect and restore the existing species, habitats and ecosystems in the city by creating ecologically valuable green spaces, such as public or private green spaces (i.e., gardens, parks, green alleys and streets, green roofs) and green buffer zones (i.e., green belts, green wedges, green ways, green fingers). These green spaces: (i) Bring nature into city life; (ii) Make urban places more attractive and pleasant; (iii) Ameliorate the negative impacts of urban development; (iv) Offer recreational opportunities, and; (v) Provide a habitat for wildlife and aquatic life (Coplak and Raksanyi, 2003; Jabareen, 2006; Convery *et al.,* 2008).

Renewable energy and waste management: As a result of growing demand for non-renewable resources, a renewable approach to resource use is essential for developing sustainable communities. As stated by Wheeler, (2013) “reduction, reuse, and recycling” are the 3R strategies for sustainable resource use. Renewable energy technologies can be summarised as: hydropower, biomass energy, geothermal energy, wind power, solar energy, and photovoltaic technologies. Additionally, another approach is waste management practices, such as landfill, incineration, biological treatment, zero waste, recycling-orientated eco-industrial parks and environmental taxes, law and policies (Davidson, 2011).

Environmental justice and social equity: Existing urban development policies reflect the inequities and discrimination between the lifestyles of the rich and poor at both national and global levels. One of the principles of sustainable development is to protect public health and welfare by managing the Earth's natural resources in an equitable manner. The strategies for creating well-balanced and sustainable communities can be summarised as: (i) Increasing affordable housing; (ii) Providing efficient transportation and easier access to public amenities; (iii) Promoting local economic growth through increased job opportunities; (iv) Providing environmental quality and protection, and; (v) Improving community participation into decision-making processes (Agyeman and Evans, 2003; Wheeler, 2013).

Economic development: As stated by Pearce and Barbier (2013, p.160), the sources of environmental problems lie in the failure of the economic system while providing valuable environmental services and functions. Creating a sustainable economy promotes: (i) Clean/green technologies (i.e., Silicon Valley in California, USA); (ii) Renewable energy sources; (iii) Green business and job initiatives; (iv) Green tax policies; (v) Green infrastructure, and; (vi) Walkable, mixed-use and transit-oriented real estate developments (Nixon, 2009).

In recent years, cities are adopting sustainable development policies into their urban plans. Table 1 provides a brief summary of the best practices of urban sustainability at different spatial scales.

For a sustainable built environment, it is necessary to regulate the natural processes and control the scale of human activities; therefore, environmental processes need to be integrated into the planning process. This integration is important in terms of understanding the physical characteristics of the developed areas as well as recognising the mechanism of the environment, its potential, limitations and risks in the planning process (Lein, 2003). In this respect, ecological planning is a fundamental approach to the sparing and efficient use of natural resources while adopting human activities in a less harmful way to the environment (Clini *et al.,* 2008).

Ecological Planning and Sustainable Cities

According to Downton, (2009), "the eco-city, or eco-polis, is the next, and perhaps most important step in the evolution of urban environments' sustainability: built to fit its place, in co-operation with nature rather than in conflict; designed for people to live whilst keeping the cycles of atmosphere, water, nutrients and biology in healthy balance; empowering the powerless, getting food to the hungry and shelter to the homeless".

Ever since the beginning of urban settlements, planners, architects, landscape architects, urban theorists and historians have sought ways of integrating nature into the built environment. The evolution of ecological planning can be traced back to the early works of Frederick Law Olmsted, Ebenezer Howard, Frank Lloyd Wright, Patrick Geddes, Lewis Mumford and Ian McHarg. Frederick Law Olmsted, (2013), the founder of landscape architecture, exhibited a concern for the preservation of the natural beauty and ecological function in the city, which this concern resulted in the development of several successful national park systems. Afterwards, Ebenezer Howard, (2010) expanded this idea further. Howard's garden city theory provided an inspiration to introduce an ecological approach to urban planning, and proposed to bring nature back to cities by outlining a self-sustaining city model surrounded by greenbelts (Wong and Yuen, 2011). Frank Lloyd Wright, (2012), focusing on organic architecture, developed the idea of using nature as a basis for the architectural approach. Wright's designs used the built environment in harmony with its natural surroundings. Patrick Geddes developed the bioregionalism theory, proposed the idea of integrating people, commerce, and land into a regional context based on an ecological balance (Bonan, 2008). Afterwards, Lewis Mumford, (2010) expanded Geddes's idea further by introducing the idea of a greenbelt community. The greenbelt communities were seen as providing a limit on the growth of population and on the physical breadth of a city. Ian McHarg proposed the methodology of ecological land use planning that links ecological thinking to the planning problems and design practices (Herrington, 2010). McHarg's theory of ecological land use planning developed a model called the layer-cake, which overlays suitability maps of different land use patterns in order to identify ecologically sensitive places and provide strategies based on the analysis (Steiner, 2011). This model also provides a theoretical basis for the geographic information systems (GIS) (Steiner, 2000; Yigitcanlar *et al.,* 2007).

In the 1980s, the environmental movement emerged into a broader context. Great technical advances were made in the harnessing of solar and wind energies as renewable sources of power, and many environmentally friendly projects were undertaken. These ideas were extended in the 1990s and resulted in the emergence of the eco-city concept, which aims to create liveable and walkable communities. By the beginning of the twenty-first century, ecological planning emerged as an expression of a sustainability world-view, which seeks to integrate the human and natural ecosystems. All of the abovementioned theories laid the foundation of the ecological planning theory and they additionally contributed to shaping many other important planning concepts (Shu-Yang *et al.*, 2004; Ahern, 2013).

As stated by Steiner, (2000), planning is "a process that uses scientific and technical information to build consensus among a group of choices". Ecology is the study of interaction between living organisms and their environments. Ecological planning then is defined as the use of biophysical and socio-cultural information derived from this interaction as decision- making opportunities and constraints in the management of ecological systems. Ecological planning is a broad concept based on strategies and methods to create green, safe, vibrant and healthy urban environments

Table 1: Exemplar best practices on urban sustainability (derived from McDonough and Partners, 1992; Newman and Jennings, 2008; Danish Architecture Centre, 2012; BioRegional Development Group, 2012; City of Freiburg, 2012)

Scale	Project	Background	Targeted Sustainability Goals	Project Website
Building	Germany: Commerzbank Headquarters	An ecological skyscraper	▪Provide natural day lighting and ventilation through the sky gardens and operable windows ▪Maximise energy efficiency through double skin facades and the use of water-filled chilled ceilings for cooling ▪Maximise water efficiency through grey water recycling	http://sustainability2009.commerzbank.com/reports/commerzbank/annual/2009/nb / English/3060/commerzbank-tower_-the-worlds-first-green-building.html
District	England: Cleveleys New Wave Project	A flood and coastal defence strategy plan	▪Break flood waters by building a wave of concrete stairs ▪Waste management by reusing the materials from the old sea wall ▪Provide a pedestrian promenade with a diverse variety of leisure and recreational activities	http://data.prismanet.gr/aspis-case-studies/view.php?id=64 http://www.urbanecology.org.au/eco-cities/christie-walk
District	Australia: Adelaide Christie Walk Eco-Village Project	An environmentally friendly neighbourhood	▪Reduce energy consumption through passive design, use of heat-efficient materials and vegetation ▪Proximity to services and public transport ▪Waste reduction and recycling ▪Improve water consumption through sustainable stormwater management ▪Provide on-site food production with creation of communal gardens	http://www.advancedfp7.eu/Home/AD-Projects-Map/Model-City-Mannheim
City	Germany: Model City Mannheim (MOMA)	A smart city that promotes energy efficiency by using solar energy and smart control technologies (i.e. Energy Butler system)	▪Connect every household with a smart-energy network ▪Raise the awareness of households about their energy habits and general energy prices ▪Help households to cut their energy bills by using energy efficient technologies ▪Reduce the energy prices	http://library.tac-atc.ca/proceedings/2002/calgary.pdf http://gec.jp/gec/EN/Activities/2005/Eco-Towns/GEC.pdf http://www.greenhouse.org.za
City	Canada: Calgary's C-Train Ride the Wind Program	A wind-powered light rail transit system	▪Provide sustainable modes of transportation ▪Provide a better air quality by reducing greenhouse gas emissions ▪Reduce car dependency	http://ww.ecotippingpoints.org/our-stories/indepth/germany-freiburg-sustainability-transportation-energy-green-economy.html

City	Japan: Kawasaki Eco Town Program	Zero waste industrial ecosystem	▪Reduce greenhouse gas emissions ▪Energy conservation ▪Waste management by turning one's waste into another's raw material	http://www.davidrisstrom.org/100GreenAchievements/100GA-MelbournePrinciples.html
City	South Africa: Johannesburg Green House People's Environmental Centre Project	Community involvement and education with urban gardening and green building principles	▪Provide an environmental demonstration and training centre for the citizens through small community gardens ▪Enhance the quality of community's life by providing them a sustainable living such as organic farming, medicinal herb gardening	http://www.mcdonough.com/speaking-writing/the-hannover-principles-design-for-sustainability/#.VHuxvYun38s
City	Germany: Freiburg Green City	The green and solar capital of Germany	▪Sustainable economy (environmental industry and research, eco-industrial tourism) ▪Sustainable mobility (environmentally compatible modes of transport) ▪The city's resource capital: nature (parks and nature conservation areas, emission control, soil protection, premium quality water) ▪Sustainable urban development (far-sighted planning and citizen participation) ▪Citizen commitment (environment education)	http://www.wpi.edu/Pubs/E-project/Available/E-project-121312-175421/unrestricted/One_Planet_Living_for_WPI.pdf
Global	The Melbourne Principles for Sustainable Cities by the United Nations Environment Programme	Creating environmentally healthy, vibrant and sustainable cities	▪A long-term sustainability vision ▪Economic and social security ▪Biodiversity and ecosystem conservation ▪Minimise the ecological footprint of cities ▪Model cities as ecosystems ▪Provide a sense of place ▪Empower people and foster participation ▪Cooperative networks towards sustainability ▪Sustainable production and consumption ▪Provide a good urban governance	
Global	The Hannover Principles by William McDonough and Michael Braungart	Designing for sustainability	▪Rights of humanity and nature to co-exist ▪Interdependence between humans and nature ▪Respect relationships between spirit and matter ▪Responsibility for the consequences of design ▪Safe objects of long-term value ▪Eliminate the concept of waste ▪Rely on natural energy flow ▪Understand the limitations of design ▪Share knowledge for constant improvement	
Global	The One Planet Living Framework by BioRegional Development Group and World Wildlife Fund	A vision for sustainable world	▪Zero carbon ▪Zero waste ▪Sustainable transport ▪Sustainable materials ▪Local and sustainable food ▪Sustainable water ▪Land use and wildlife ▪Culture and heritage ▪Equity and local economy ▪Health and happiness	

(Roseland, 1997). It is an important planning tool in the establishment of sustainable cities. As stated by Ndubisi, (2002), "ecological planning is more than a tool: it is a way of mediating the dialogue between human actions and natural processes based on the knowledge of the reciprocal relationship between people and the land. It is a view of the world, a process and a domain of professional practice and research within the profession of planning". According to Shu-Yang *et al.,* (2004), the key characteristics of ecological planning can be summarised as below:

Meeting the inherent needs of human beings: Ecological planning is an essential tool for enhancing the sustainability of human enterprise through finding environmentally friendly ways of manufacturing goods, constructing buildings and planning recycling-orientated enterprises to reduce ecological damage as much as possible.

Moving towards resource sustainability: Ecological planning promotes the urban form that requires minimum energy and resource input as well as minimises waste generation and ecological damage through efficient use, re-use and recycling.

Maintaining ecological integrity: Ecological planning integrates human activities with the dynamics of natural flows and cycles of materials and energy by developing solutions to particular planning issues. This can be achieved through defining the carrying capacity of ecosystems for the proposed human activities.

Emulating natural ecosystems: Another goal of ecological planning is to emulate natural ecosystems when planning for anthropogenic activities, so that the resulting effects will be relatively 'natural'. For instance, this can be achieved through developing a symbiotic industrial system that refers to an integrated process in which the waste of one process becomes a resource for another.

In many parts of the world, new or existing developments move towards a more ecological direction. As presented in Table 2, many cities develop integrated solutions to the major environmental challenges of today and transform into sustainable and self-sufficient communities.

Towards Sustainable Urban Ecosystems

The main purpose of all the aforementioned efforts is modelling cities as "sustainable ecosystems, which are ethical, effective (healthy and equitable), zero-waste, self-regulating, resilient, self-renewing, flexible, psychologically-fulfilling and cooperative" (Newman and Jennings, 2008). In this regard, cities need to be considered as ecosystems in order to develop sustainable development policies and programmes.

An ecosystem is a dynamic ecological system that consists of a community of plants, animals and microorganisms living in a particular environment that interacts as a functional unit with their non-living environment and anthropogenic components. They provide a variety of services to people including: (i) Provisioning services (i.e., food, fibre, fresh water and fuel); (ii) Regulating services (i.e., air quality maintenance; climate regulation, water purification and flood control); (iii) Cultural services (i.e., educational, recreational and aesthetic experiences), and; (iv) Supporting services (i.e., nutrient cycling, soil formation, primary production) (Rebele, 1994; Millennium Ecosystem Assessment, 2005; Zhang *et al.*, 2006; ICSU/UNESCO/UNU, 2008).

As presented in Fig. 2, ecosystems are strongly influenced by the human social system, which is shaped by peoples' population, psychology and social organisation. Values and knowledge influence how individuals interpret and process the information while translating it into action. Social organisations and institutions specify acceptable behaviours and norms; furthermore, technology defines the possible actions. As a closed loop system, the ecosystem provides services to the human social system by moving energy, materials and information to meet their needs. In contrast, energy, materials and information resulting from human activities move from the social system to the ecosystem by damaging the ability of the ecosystem to continue providing services for the people (Marten, 2001; Childers *et al.*, 2014).

Briefly, the city as a place where 'nature and artifice meet' (Levi-Strauss, 1961), is a dynamic biological organism that consists of a human population and built-up environment that are highly dependent on nature. In other words, a city is the most dramatic manifestation of human activities on the environment (Ridd, 1995). As stated by Alberti, (2005), this human-dominated organism degrades natural habitats, simplifies species composition, disrupts hydrological systems, and modifies energy flow and nutrient cycling. To examine this interaction, it is required to consider cities as 'urban ecosystems', in other words, as defined by Alberti, (1996) "urban ecological spaces", with their biological and physical complexities that interact with each other.

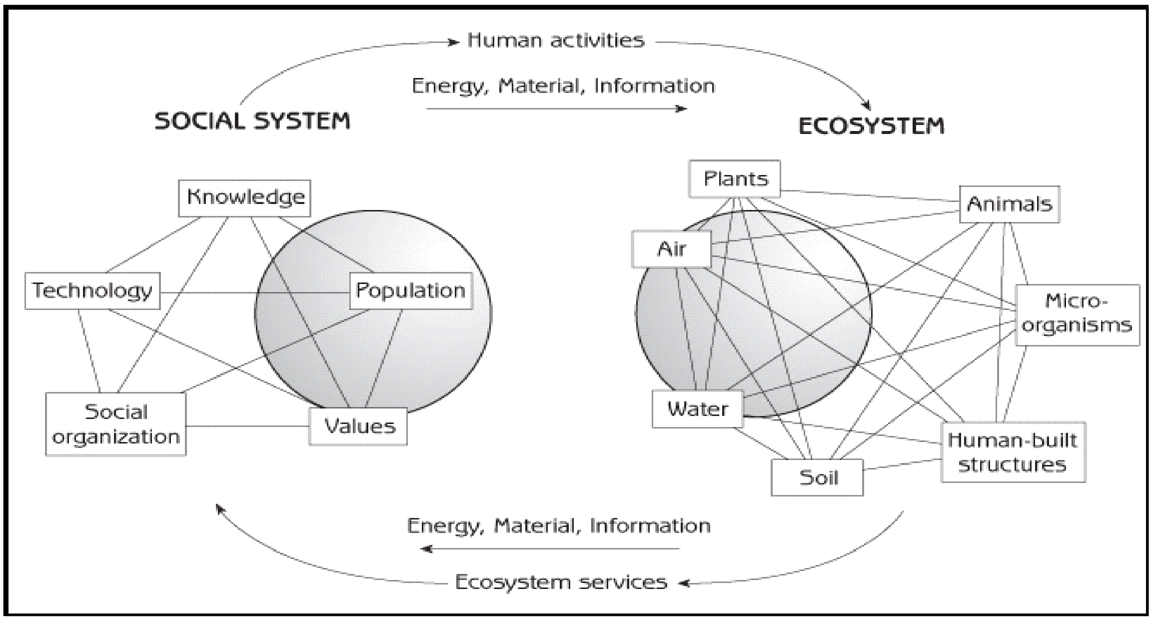

Fig. 2: Interaction between the ecosystem and human social system (Marten, 2001)

Table 2: Exemplar best practices on ecological planning

Project	Ecological Planning Approaches	Achievements	References
Germany:Stuttgart's climate planning strategy	The use of green infrastructure such as: ▪ventilation lanes (tree-flanked arteries) ▪climate-relevant open spaces such as public parks ▪roof greening ▪facade greening	Turning an industrial city into a cool and green city: ▪manage urban heat island with natural wind patterns and vegetation ▪protect biological diversity ▪improve air quality ▪reduce traffic related noise pollution ▪provide large and connected green spaces for cooling and shading	Danish Architecture Centre (2012)
South Korea: The Cheonggye River Restoration Project	▪Stream design (water supply and Management) ▪Environmentally friendly waterfront by landscape design ▪Environmentally friendly transport system ▪High-quality modern residences ▪Restoration of historical relics	Transforming a freeway into a river and public park: ▪reduce the heavy vehicular traffic ▪provide a natural drainage system ▪prevent flooding risk due to impermeability ▪improve water quality and nourish wildlife by landscape planning ▪provide a recreational waterfront for inhabitants	Danish Architecture Centre (2012)
UK:The BedZED (Beddington Zero Energy Development) Eco-Village	▪Energy efficient buildings ▪Water saving appliances ▪Use of renewable energy sources ▪Waste recycling ▪Biodiversity plan for the urban natural environment ▪Green transport plan (public transport, rental car clubs, cycle routes and storage facilities)	An eco-friendly housing development: ▪zero emission neighbourhood ▪resource-efficient way of life ▪enhanced the biodiversity and natural amenity value ▪less car dependent lifestyle	BioRegional Development Group (2002)

Sweden:Malmo Bo01 Ecological District	▪Energy efficient buildings ▪Wind parks that supplies the electricity of the area ▪Recycling of food waste as biogas for electricity and heat generation ▪Rainwater management through green roofs, ponds, wetlands and rain water channels ▪Green spaces such as parks, woodlands, flower gardens and green roofs ▪Built-in nesting boxes for birds ▪High priority of designing pedestrian and cycle tracks	An eco-friendly housing development: ▪increase the biological diversity ▪stormwater management ▪use of renewable sources ▪green transport ▪waste management ▪energy conservation ▪green architecture ▪ecologically aesthetic urban environment ▪open urban spaces for recreational activities	Hancock (2001) Danish Architecture Centre (2012)
Germany:Emscher Park Brownfield Redevelopment	▪The use of green infrastructure such as greenbelts, public gardens ▪Thematic tourist driving and biking route called 'route of industrial culture' ▪Multi-use urban waterfront including energy-efficient offices ▪Adaptive reuse of industrial buildings ▪Recycle and reuse of industrial wastes in the park design ▪Walls used for rock climbing	Turning a degraded industrial region into a regional network of open spaces: ▪enhance the ecological health of Emscher river and its tributaries ▪regenerate the degraded landscape ▪provide social and cultural activities ▪preserve the historic industrial heritage ▪provide local employment	Danish Architecture Centre (2012)
USA:New York High Line Park	▪Native and low-maintenance landscape design ▪Green roof and technologies for water drainage ▪public open spaces for people ▪Energy-efficient lighting design ▪benches and other structures made of wood from certified sustainable forests	Turning an old elevated railway into a green corridor: ▪better microclimate and environmental conditions ▪an urban habitat for wildlife and people ▪urban regeneration and adaptive reuse ▪an economically productive neighbourhood	Danish Architecture Centre (2012)
USA:Seattle Green Factor	A scoring system which calculates ecologically effective urban area by assigning an ecological value to the each type of existing landscape element such as: ▪groundcovers, shrubs, trees ▪porous pavements ▪green roofs ▪green walls ▪water features, rain gardens ▪drought tolerant plants	A parcel scale landscape management strategy for ecological city vision: ▪promote urban green spaces ▪improve the ecological function and richness of the urban environment ▪urban heat island management ▪stormwater management ▪soil protection	SenStadtUm (2012) Seattle DPD (2012)

According to Capra, (2002), “to build a sustainable society for our children and future generations - the great challenge of our time-we need to fundamentally redesign many of our technologies and social institutions so as to bridge the wide gap between human design and the ecologically sustainable systems of nature”.

A sustainable urban ecosystem can be characterised as an ecosystem that exists in and around an urban settlement that manages the natural environment by: (i) Using natural resources effectively; (ii) Producing zero waste through recycling and reusing; (iii) Maintaining the ecological functions and processes through self-regulation; (iv) Providing resilience against environmental disturbances, and; (v) flexibility in response to these disturbances (Bolund and Hunhammar, 1999; Berkowitz *et al.,* 2002). As human existence depends on the biological diversity of ecosystems, ecosystem goods and services is required to be managed in a more sustainable way. Sustainable management of the urban ecosystem is centrally based on a number of principles (Meier, 1984; Mcmanus and Haughton, 2006; Newman and Jennings, 2008; Kowarik, 2011; United Nations, 2011):

Providing a long-term city vision: The development of a long-term city vision emerges as a key element in providing a basis for setting sustainability goals and action plans by defining the ecological, social and economic characteristics of the community and their constraints. Furthermore, a vision serves as a guiding framework for future decision-making and gives communities a chance to rebuild their cities in a sustainable direction.

Achieving long-term economic and social security: Cities need to integrate their social values and economies into a sustainable framework. To achieve economic and social security, human communities and institutions need to become more equitable, resilient, flexible and ecologically minded by transforming their economies to serve bioregional and local community priorities.

Protecting and restoring biodiversity and natural ecosystems: Cities need to be managed to provide opportunities for biodiversity conservation through the creation of protected areas like gardens, parks, greenways, wildlife corridors and biosphere reserves. Furthermore, ecological architecture and infrastructure, such as zero energy buildings, green roofs, stormwater management and water sensitive urban design also enhance biodiversity and natural ecosystems.

Minimising the ecological footprint of cities: As an indicator towards sustainability, the ecological footprint represents the carrying capacity of an urban area exposed to resource consumption and waste disposal. Cities need to reduce their ecological footprints through ecosystem assessments, managing population growth and city sprawl, reducing their consumption patterns.

Building a sense of place that reflects the distinctive characteristics of cities: The way of designing cities and lifestyles, social and political processes, and institutions within need to match the distinctive patterns of the places. Therefore, cities need to build a sense of place by protecting cultural, historic and natural heritage, designing with natural processes, connecting the urban form with its bioregion and using cultural practices and the arts to deepen the sense of place.

Providing sustainable production and consumption: Cities need to minimise their resource use, toxic materials, waste emissions and pollutants for bringing a better quality of life. Therefore, they need to increase the carrying capacity of ecosystems through the use of environmentally sound technologies and effective demand management of resources.

Enabling cooperative networks towards a sustainable future: An effective partnership between government, business and the community is necessary for finding innovative solutions to the issues of sustainability. Furthermore, building cooperative networks is essential for creating resilient cities and making people more able to respond to feedback and take appropriate action.

In sum, examining the city as an ecosystem and understanding the interaction between urban ecosystem and human activities is an important factor to take into consideration while transforming cities into sustainable communities. Thus, a holistic sustainability assessment approach is required in order to monitor this interaction over time and geographic scales.

Urban Ecosystem Sustainability Assessment

Urban ecosystem sustainability assessment plays an important role in the decision-making and urban planning processes at the national, regional or local levels. The main purposes of urban ecosystem sustainability assessment are to: (i) Define sustainable development targets and assess progress made in meeting those targets; (ii) Revise the effectiveness of current planning policies and help in making the necessary corrections in response to changing realities, and; (iii) Make comparisons over time and across space by performance evaluation as well as provide a basis for planning future actions. In other words, urban ecosystem sustainability assessment is a powerful tool to connect past and present activities to future development goals (Hardi *et al.,* 1997; Lamorgese and Geneletti, 2013).

Urban ecosystem sustainability assessment is performed via applying different approaches and tools ranging from indicators to comprehensive models. The selection of the appropriate assessment method depends on the subject of the assessment, the nature and complexity of the environmental impacts as well as time and scale aspects (ARE, 2004). Urban ecosystem sustainability assessment methods are categorised in three groups by Waheed *et al.,* (2009), as follows:

First category includes assessment frameworks, which are basically integrated and structured procedures that assist in the comparison of proposed project and policy alternatives based on their environmental impacts (i.e., Environmental Impact Assessment-EIA and Strategic Environmental Assessment-SEA).

Second category includes analytical evaluation tools, which are used to conduct analysis in order to support decision-making by finding potential solutions to specific problems within the framework. These tools are divided into two sub-categories:
- Reductionist tools use a single measureable indicator or dimension or objective or scale of analysis or time horizon for evaluation (i.e., economic tools such as Cost Benefit Analysis-CBA and Whole Life Costing-WLC, biophysical models such as Material Flow Analysis, Ecological Footprint and Energy Accounting, indicators/composite indices), and;
- Non-reductionist tools follow a series of methodological choices, which are subjective and influenced by the analyst (i.e., Multi-Criteria Analysis-MCA).

Third category includes sustainability metrics, which are divided into three sub-categories:
- Ecosystem-scale, such as Ecological Footprint Analysis, Environmental Sustainability Index-ESI and Wellbeing Index-WI;
- Building-environment scale, such as green building rating systems, and;
- Building scale, such as Net Energy, Zero Energy, and Renewable Energy Balance-REB.

As another categorisation shown in Fig. 3, made by Ness *et al.,* (2007), urban ecosystem sustainability assessment methods are divided into three categories, as follows:
- First category includes product-related assessment tools, which investigate the flows related to production and consumption of goods and services. The most established example is the 'Life Cycle Assessment', which evaluates resource use, and resulting environmental impacts of a product throughout its lifecycle and the outputs influence environmental policies and regulations.
- Second category includes integrated assessment tools, which investigate policy change or project implementation through developing scenarios. For instance, 'Environmental Impact Assessment' and 'Strategic Environmental Assessment' are commonly used examples for assessing the environmental impacts of development projects or strategic decisions in order to reduce their potential externalities.
- Third category includes sustainability indicators and composite indices, which are increasingly recognised as useful assessment tools. They provide guidance in the urban planning process by detecting the current sustainability performance of an urban setting by assessing the impacts of development pressure on natural resources.

As can be seen from the aforementioned categorisation of the assessment methods, the spatial scale is an important aspect of assessment in detecting urbanisation impacts on natural resources and ecosystems. Scale is linked to variation and predictability of the assessment. The amount of detail determines the accuracy of the assessment. Furthermore, the scale of the assessment influences both the definition of the environmental issue and the range of possible actions and policy responses (Weins 1989; Levin 1992; Millennium Ecosystem Assessment, 2003). While conducting sustainability assessment at larger-scales, there are usually limitations in collecting reliable and accurate information. For this reason, the micro-scale is the ideal scale to detect the environmental stress in an urban ecosystem by providing more detailed data and preventing loss of detail in collecting coarser spatial data.

The impacts and complexity of environmental issues have different temporal and spatial characteristics. Many problems, which emerged at the local level several years ago, have become national and global

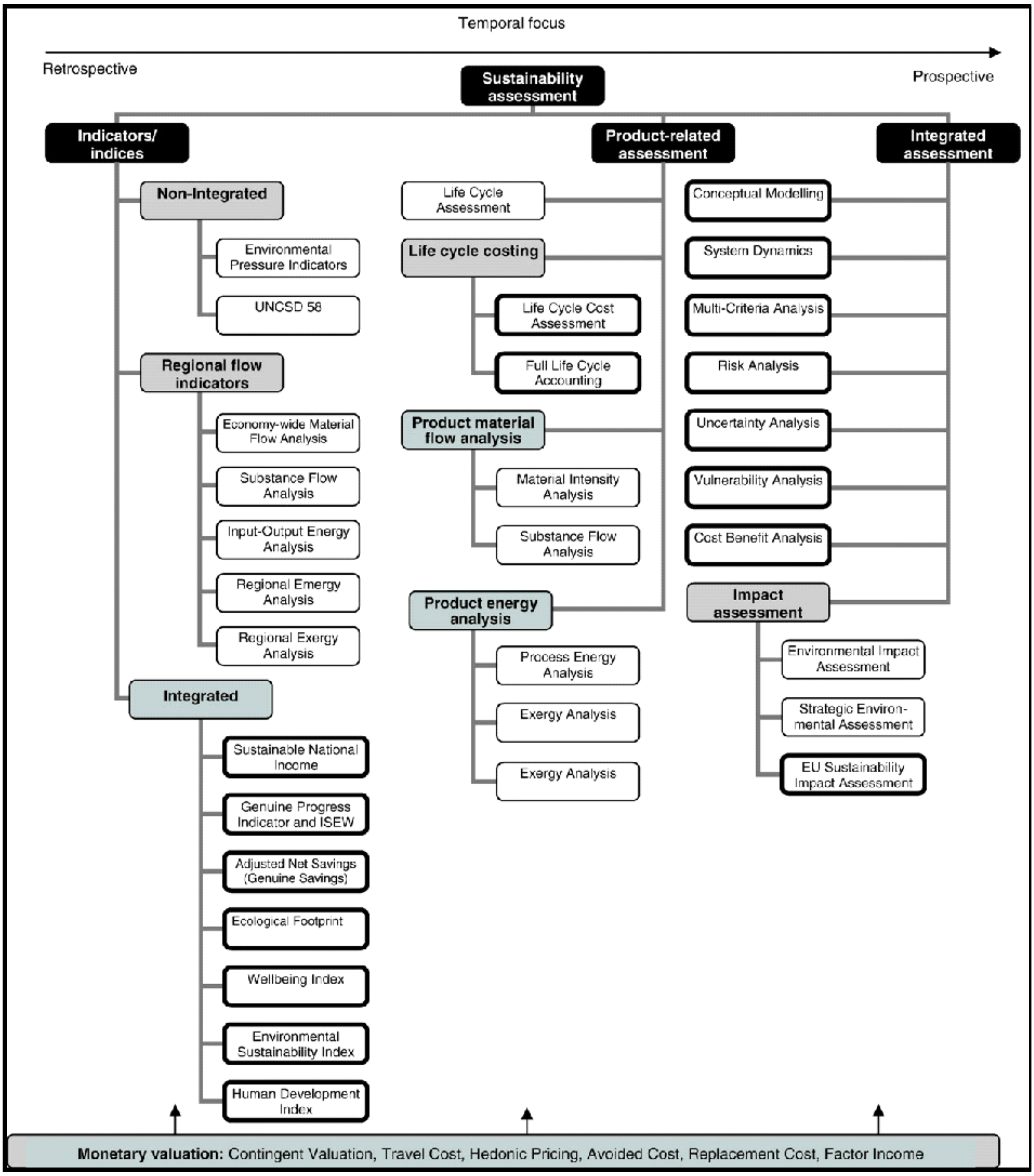

Fig. 3: Framework for urban ecosystem sustainability assessment tools (Ness *et al.*, 2007, p. 500)

problems today. Therefore, sustainability assessment needs to be carried out at different scales in order to evaluate environmental problems. For instance, as seen in Fig. 4, climate change is a global environmental issue; however the policy responses and strategies are developed at the national levels and applied at the local level. In a similar manner, it is difficult to analyse the state of the environment and natural resources at regional scale, hence, regions needs to be classified on a broader scale. Additionally, ecosystems are the local units where the causes and outcomes of implemented policies can be assessed (Winograd, 1997; Chapin *et al.*, 2010).

It is clear from the above example that various spatial scales of human activities affect urban ecosystems. As stated by Alberti, (2008), “the smallest spatial unit in the urban ecosystem allows for producing socioeconomic and biophysical information that varies from household and building levels to street and parcel levels. These parcels then combine to create new functional units as suburbs and neighbourhoods that interact with regional and national scales”. In this context, as a result of the multi-scale characteristics of environmental problems, detailed and up-to-date micro-scale data is crucial in order to assess national and global environmental change in urban ecosystems.

As presented in Table 3, there are many countries that are making progress on the development of urban ecosystem sustainability assessment tools at different spatial scales.

Over the past several years, there has been a significant increase in the development of urban ecosystem sustainability assessment tools in order to provide guidance for the evaluation of the environmental impacts of existing and new urban developments. As stated by Karol and Brunner, (2009), even though they use different assessment themes and sub-themes, they outline the common sustainability principles, such as conservation of native vegetation, reduction of non-renewable energy use, waste reduction, water efficiency, high quality public transport and social safety. Therefore, they need to be integrated into the policy and decision-making to build sustainable urban environments.

Urban ecosystem sustainability assessment provides a systematic approach to policy and decision-making during the different stages of sustainable development. The purpose of assessment is to assist the planning authorities in the evaluation of economic, social and environmental impacts of the projects. Urban ecosystem sustainability assessment can be used in policy and decision-making at three stages: (i) Ex-ante assessments carried out at the beginning of the project in order to analyse the potential negative and positive impacts of proposed project options and help in choosing the best-fit option; (ii) Concurrent

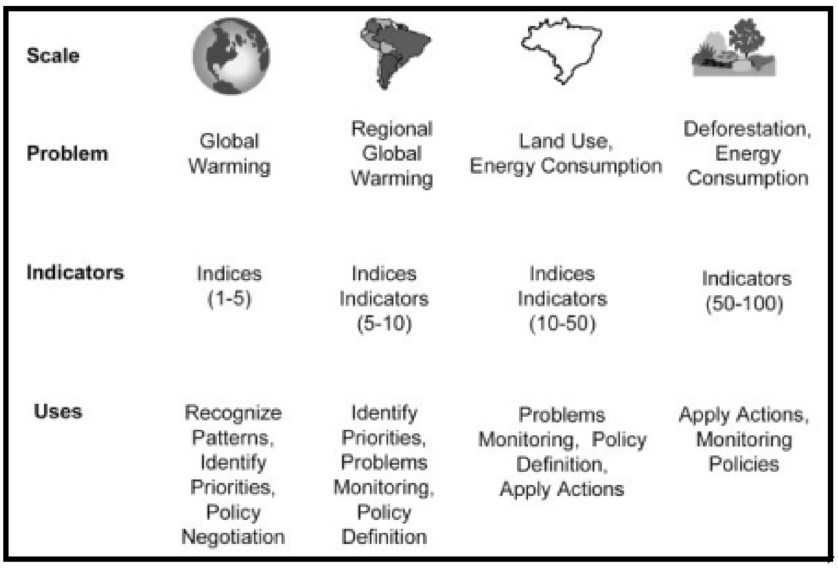

Fig. 4: Scales and uses of sustainability assessment (Winograd, 1997)

Table 3: Summary of urban ecosystem sustainability assessment tools

Assessment Tool	Context	Themes	References
Australia:VicUrban Sustainability Charter	A decision-making and monitoring tool used at three stages of development: project vision and goal setting, project design, project delivery and final reviews	▪Commercial success ▪Community well-being ▪Environmental leadership ▪Urban design excellence ▪Housing affordability	VicUrban (2006)
USA:The Leadership in Energy and Environmental Design (LEED)-Neighbourhood Developments	A green certification tool aims to develop a national set of standards for neighbourhood design based on the combined principles of smart growth, urbanism and green building	▪Smart Location and Linkage ▪Neighbourhood Pattern and Design ▪Green Infrastructure and Buildings ▪Innovation and Design Process ▪Regional Priority Credit	U.S. Green Building Council (2005)
Australia:The Australian Housing and Urban Research Institute (AHURI)	A performance assessment framework for the existing developments	▪Housing Affordability ▪Neighbourhood and Community safety and satisfaction ▪Transportation ▪Environment - Biodiversity ▪Environment - Energy ▪Environment - Other resources ▪Environment - Wastewater and stormwater control	Blair *et al.* (2004)
Japan:The Comprehensive Assessment Systemfor Building Environmental Efficiency (CASBEE)	A tool for evaluating urban development and buildings in terms of their environmental performance	▪Natural Environment (microclimates and ecosystems) ▪Service functions for the designated area ▪Contribution to the local community ▪Environmental impact on microclimates ▪Social infrastructure ▪Management of the local environment	CASBEE (2007)
UK:The Building Research Environmental Assessment Method (BREEAM)	An environmental assessment rating system for buildings including: offices, homes, industrial units, retail units and schools	▪Energy ▪Transport ▪Pollution ▪Materials ▪Water ▪Land Use and Ecology ▪Health and Wellbeing ▪Management	BREEAM (2006)
Australia: The Green Starof the Green Building Council of Australia (GBCA)	A green star rating tool for assessing environmental impacts related to building design	▪Management ▪Indoor Environmental Quality ▪Energy Consumption ▪Transport ▪Water ▪Materials ▪Land use & Ecology ▪Emissions ▪Innovation	Tan (2006)
Australia: The National Australian Building Environmental Rating System (NABERS)	A performance-based rating system for existing buildings	▪Energy ▪Water ▪Waste ▪Indoor environment	Seo (2002)

Hong Kong:The Building Environmental Assessment Method (HK-BEAM)	A rating tool that provides a guidance to developers, designers on green development practices	▪Site aspects ▪Materials aspects ▪Energy use ▪Water use ▪Indoor environmental quality ▪Innovations	HK-BEAM (2004)
The European Commission:Building Environmental Quality for Sustainability through Time (BEQUEST) international framework	A tool for sustainable urban development, helps decision-makers to examine the strengths, weaknesses and gaps in development projects	▪Development activity ▪Environmental and societal issues ▪Spatial level ▪Time scale	Hurley and Horne (2006)
The European Commission:System for Planning and Research in Townsand Cities for Urban Sustainability (SPARTACUS)	An integrated land use/transport model for analysing urban sustainability	▪Air pollution ▪Resource consumption ▪Health ▪Equity ▪Opportunities	European Commission (1998)
The European Commission:Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS)	A model system for defining sustainable long-term urban strategies and demonstrating their effects	▪Global climate change ▪Air pollution ▪Consumption of natural resources ▪Environmental quality ▪Health ▪Equity ▪Opportunities ▪Accessibility and traffic ▪Total net benefit from transport	Spiekermann and Wegener (2007)
UK:Environmental Impact Estimating Design Software (ENVEST)	A software tool that estimates the life cycle environmental impacts of a building from the early design stage	▪Resource (Fossil fuel depletion/ extraction, minerals extraction, water extraction) ▪Environmental loadings (Climate change, acid deposition, ozone depletion, human toxicity, low level ozone depletion, eco-toxicity, eutrophication, waste disposal)	Seo (2002)
Canada:The ATHENA Environmental Impact Estimator	A Life cycle assessment-based environmental decision support tool for buildings	▪Embodied primary energy use ▪Global warming potential ▪Solid waste emissions ▪Pollutants to air ▪Pollutants to water ▪Natural resource us	Seo (2002)
UK: The South East England Development Agency (SEEDA) checklist	A sustainability checklist for developments in order to highlight best practice & regionally specific sustainability & planning issues	▪Climate change & energy, transport & movement, ecology, energy & water efficient building ▪Resources protection ▪Community support, sensitive place making ▪Support for business	Karol and Brunner (2009)
The Netherlands: Eco-Quantum	A tool calculating the environmental performance of a building over its total life span	▪Resources ▪Emissions ▪Energy ▪Waste	Bruno and Katrien (2005)
Norway: Eco-Profile	An environmental assessment tool for buildings	▪External Environment ▪Resources ▪Indoor climate	Pettersen (2000)

assessments carried out during the process of developing the project in order to monitor the progress towards meeting sustainability goals, and; (ii) Ex-post assessments provide an evaluation of the consequences of the selected project and policies after a particular period of time in order to mitigate their negative impacts through revisions (Abaza, 2003; LUDA, 2012).

In order to assess environmental performance, examine ecological limits as well as provide the long-term protection of environmental quality, urban ecosystem sustainability assessment is a potential planning tool for policy and decision-making. As outlined by the UNEP, (2004), integration of urban ecosystem sustainability assessment into policy and decision-making process provides the following benefits:

Supporting sustainable development: The assessment results: (i) Highlight the economic, social, environmental opportunities and constraints; (ii) Organise the policy and decision-making process by reducing the complexity of each stage, and; (iii) Help governments to reach proposed sustainability targets.

Facilitating good governance and institution-building: The integrated assessment: (i) Promotes the transparency of the policy and decision-making process; (ii) Helps build social consensus about its acceptability, and; (iii) Enhances coordination and collaboration between different government ministries and bodies.

Saving time and money: The integrated assessment: (i) Strengthens the intersectoral policy coherence; (ii) Provides early warning of the potential problems, and; (iii) Minimises environmental, social and health impacts thereby reducing the costs required to remedy them.

Enhancing participatory planning for sustainable communities: The integrated assessment: (i) Increases the awareness of governments and citizens on the significance of ecosystem functioning, and; (ii) Strengthens national commitment to sustainable development.

Nevertheless, the research on employing different tools and methodologies to help policy and decision-making is still in progress. As stated by Schepelmann *et al.*, (2008), although the guideline documents in the literature often identify the required procedural steps and checklists, they provide insufficient information about the methodological and analytical guidance. As another critical issue, many urban ecosystem sustainability assessment approaches evaluate the social, economic and ecological impacts of policy and decision-making process separately; hence, they struggle to integrate their separate findings into a single framework.

An example of the methodology for urban ecosystem sustainability assessment, which measures the interaction between human and ecosystem wellbeing, as developed by the International Union for Conservation of Nature and Natural Resources consists of seven stages as follows (Guijt and Moiseev, 2001):

Determine the purpose of the sustainability assessment: In this step, the purpose and objectives of the assessment are clarified. The intended users and participants, its intended uses and methods are defined.

Define the system and goals: In this step, the geographic area for the assessment is defined. A vision and goals for sustainable development are developed and then recorded. Finally, base maps for the assessment are prepared.

Clarify dimensions, identify elements and objectives: In this step, the dimensions, which will be used for measuring performance towards sustainable development, are established. The elements for all dimensions and the objectives for each element are identified. Data collection and storage are also carried out.

Choose indicators and performance criteria: In this step, all selected indicators are explained in detail and the performance criteria for each indicator are justified.

Gather data and map indicators: In this step, the indicator scores are calculated and the scores are mapped.

Combine indicators and map the indices: In this step, the indicator scores are aggregated into an index through some methodological steps and the scores are mapped in order to explain the findings easily.

Review results and assess implications: This step involves the analysis of the results, causes and implications as well as identification of the priorities for improvement. The results of the assessment give a snapshot of the current situation and the findings help to determine the policies and actions.

Briefly, urban ecosystem sustainability assessment is a powerful tool for tracking environmental progress as well as the environmental effects of policies and actions taken for sustainable development. They provide valuable information for effective decision-making and policy formulation (Nguyen, 2004). As Devuyst *et al.,* (2001) summarise "urban ecosystem sustainability assessment aims to steer societies in a more sustainable direction by providing tools that can be used either to predict impacts of various initiatives on the sustainable development of society or to measure progress toward a more sustainable state". It is an essential process in the development of sustainable polices in terms of collecting information for the planners and decision makers concerning the severity of environmental problems and their impacts on natural environment (RCEP, 2002; Pearsall and Pierce, 2010).

Indexing Urban Ecosystem Sustainability

As defined by Newton *et al.,* (1998), "environmental indicators are physical, chemical, biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue". They reflect environmental changes over a period of time and provide information about the interrelationship between environment and human activities by underlining emerging environmental issues. Environmental indicators are categorised in several different ways. The World Resources Institute divided environmental indicators into four categories based on the human and environment interactions (Hammond *et al.,* 1995; Alberti, 1996): (i) Source indicators, which measure the depletion of resources and the degradation of biological systems (i.e. agriculture, forest, marine resources); (ii) Sink indicators, which evaluate the capacity of resources to absorb emissions and waste (i.e., climate change, acidification, toxication); (iii) Life Support indicators, which monitor the change in the state of the Earth's ecosystems and biodiversity (i.e., threatened species, special lands, oceans), and; (iv) Human impact indicators, which measure the impacts of environmental problems on public health and the quality of life (i.e., housing, waste, health, natural disaster).

According to Bakkes *et al.* (1994), environmental indicators are classified in three ways: (i) Classification by use assists to investigate the same environmental problem with different indicator sets depending on the environmental policy or scientific development; (ii) Classification by subject or theme (i.e., climate change and energy consumption) assist to investigate particular political issues, and; (iii) Classification by position in causality chains such as environmental pressures, environmental status and societal responses. The World Bank, (1997) also identified three major types of environmental indicators: (i) Individual indicator sets, which include large lists of indicators covering a wide range of issues to improve the integration of environmental concerns into policies (i.e., the OECD indicators); (ii) Thematic indicators, which include a small set of indicators to evaluate environmental policy for each of the issues (i.e., World Development indicators), and; (iii) Systemic indicators, which include one indicator to identify a complex problem (i.e., the wealth and genuine savings indicators).

The choice of appropriate environmental indicators depends on clear selection criteria. The indicator should (Newton *et al.,* 1998):

- Reflect a fundamental aspect of the environmental condition and problems;
- Be applicable to all scales of environmental issues;
- Be cost-effective as well as monitored regularly and interpreted easily;
- Be internationally comparable with other indicators;
- Provide statistically verifiable and reproducible data showing changes over time;
- Provide information that meets the policy and management needs, and;
- Track progress towards implemented significant environmental policies.

Indicators are one of the key pieces of the sustainability puzzle that helps to draw a picture of the current situation of development and reveal whether sustainability targets are being met. As stated by Gabrielsen and Bosch, (2003), environmental indicators are used for four major purposes: (i) Providing information on environmental problems to assist planners and policy-makers in evaluating their severity; (ii) Supporting policy formulation by identifying pressure factors on the environment; (iii) Monitoring the effects and effectiveness of policy implementation, and; (iv) raising public awareness on environmental issues by providing information on the driving forces of environmental impacts and their policy responses. In recent years, an increasing number of environmental indicator initiatives have been developed by international organisations. Although they are derived from different indicator datasets and developed at different scales, their common framework is based on addressing these questions: (i) What is happening to the state of natural resources; (ii) Why is it happening, and; (iii) What is being done about it (Hammond *et al.,* 1995). A brief description of major environmental indicator initiatives is identified below.

The most internationally known indicator initiative is the 'Pressure-State-Response Framework' (PSR) developed by the Organisation for Economic Cooperation and Development (OECD), which is based on 'Pressure' indicators that describe the problems caused by human activities; 'State' indicators that monitor the physical, chemical and biological quality of the environment, and; 'Response' indicators that indicate how the society responds to environmental changes and concerns (Segnestam, 2003). This framework was further extended by the European Environment Agency (EEA) as 'Driving force-Pressure-State-Impact-Response' (DPSIR), which can be widely adapted from regional to global levels to provide a more comprehensive approach in analysing environmental problems (Fig. 5). 'Driving force' indicators underlie the causes, which lead to environmental pressures and 'Impact' indicators express the level of environmental harm on the state of natural resources (Gabrielsen and Bosch, 2003). Furthermore, several international organisations have developed indicator initiatives, such as Indicators of Sustainable Development of UN Commission on Sustainable Development (UNCSD), Healthy Cities Core Indicators of World Health Organization (WHO), and Urban Indicators of UN Centre for Human Settlements (UNCHS), Local Sustainability Indicators of European Union (EU), and EUROSTAT Sustainable Development Indicators.

Moreover, as shown Table 4, several communities have developed indicator initiatives to design their local plans to achieve sustainable urban development.
Apart from these initiatives, in recent years, there has been an increasing amount of initiatives on environmental sustainability indices. For instance, the Compendium of Environmental Sustainability Indicator Collections include 426 indicators of environmental sustainability derived from the following six indices: Environmental Sustainability Index (ESI), Environmental Performance Index (EPI), Environmental Vulnerability Index (EVI), and Rio to Johannesburg

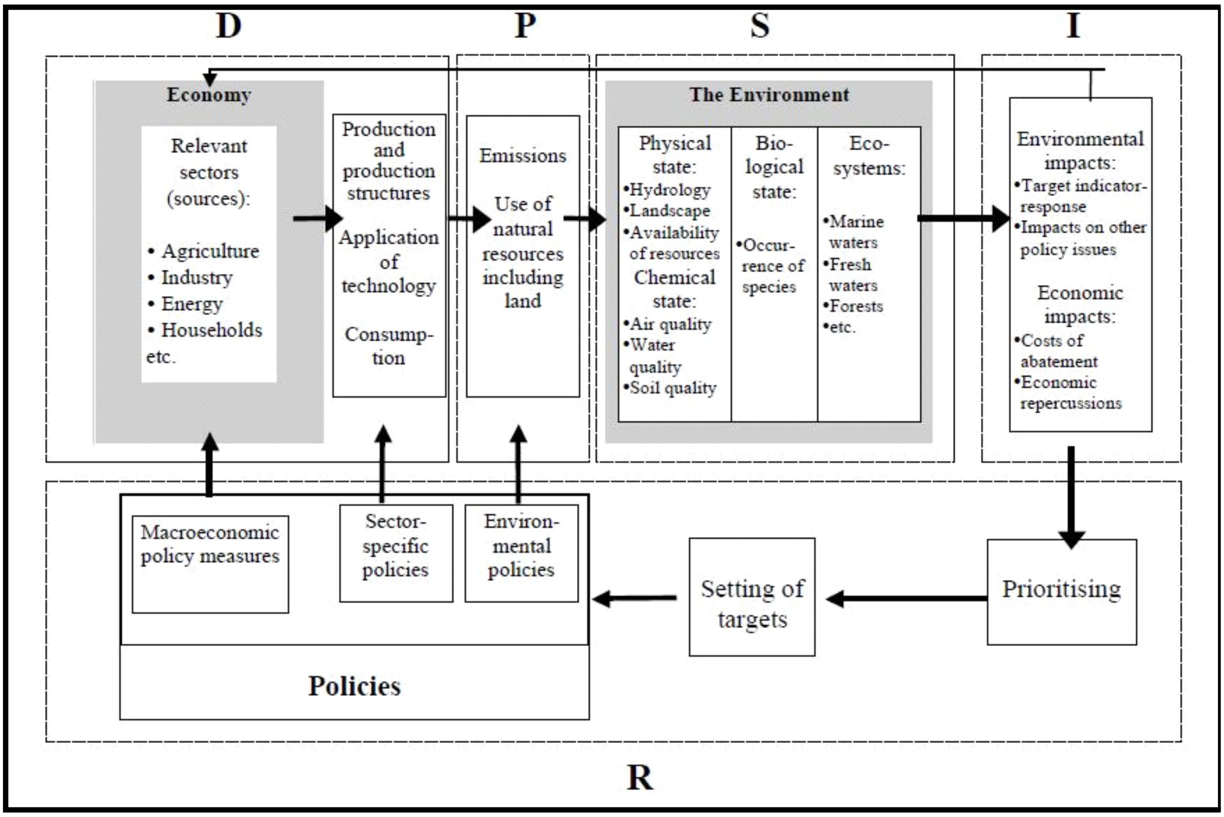

Fig. 5: The DPSIR framework (Kristensen, 2004)

Table 4: Overview of international sustainability indicator initiatives (derived from Leicestershire County Council, 2008; Vancouver City Council, 2009; London Sustainable Development Commission, 2009; Mahoney *et al.*, 2010; Sustainable Measures, 2012)

Country	Sustainability Indicator Initiative	Project Detail
Australia	City of Sydney	A city program to develop a vision, goals and strategies in the areas of environment, transport, economy, city design, culture, community and governance
	Victoria Community Indicators Project	Well-being indicators for all the local governments in the state of Victoria
	City of Melbourne	A number of environmental indicators in the areas of air quality, biodiversity, buildings, litter and transport
	City of Gosnells Sustainable Development Initiative	Environmental Management Plan 2006-2009 has objectives with measurable indicators
Canada	Sustainable Calgary	Inspired by Sustainable Seattle, this group has published several "State of Our City" reports with sustainability indicators
	Sustainable Vancouver Plan	The plan sets out nine major goal areas: climate change; environment and public health; resource conservation; transportation; economic development; land use; the built environment; social equity; and civic engagement
	City of Atlanta Sustainability Plan	A plan that encourages the community dedicated to environmental sustainability through innovative leadership
Europe	Fife Regional Council, Fife House	Sustainability Indicators for Fife lists a number of indicators including economy, environment, housing, and quality of life
	London Quality of Life Indicators	The Commission has identified 23 headline Quality of Life Indicators to monitor London's progress towards becoming a sustainable city
	Leicester Community Sustainability Indicators	A Sustainable Community Strategy sets out our priorities for improvement in Leicestershire
United States	Sustainable Seattle	Sustainable Seattle was one of the first organizations to produce sustainable community indicators grouped into four broad areas: environment, population and resources, economy, culture and society
	Sustainable Chattanooga	A Sustainability Plan focuses on environment, energy, transportation, economic development, neighbourhoods, crime and safety
	Portland Comprehensive Plan	The city has a vision and a strategic plan with sustainable development goals and indicators
	Sustainable Community Roundtable of South Puget Sound	The Sustainable Community Roundtable was one of the nation's first grassroots organizations promoting the vision and principles of sustainability
	Austin Sustainable Community Initiative	The city of Austin has compiled information and resources on 11 categories of actions to promote sustainability
	Santa Monica Sustainable City Program	The plan covers goals including resource conservation, environmental and public health, transportation, economic development, open space and land use, housing
	Minneapolis Sustainability Initiative	Sustainability Initiative is reporting on progress towards specific goals relating to housing, health and safety, equity, learning, connected communities, arts and culture, environment, and economy

Dashboard of Sustainability, The Wellbeing of Nations and National Footprint Accounts (Ecological Footprint and Bio-capacity) (SEDAC, 2007).

Yale and Columbia Universities developed the Environmental Sustainability Index (ESI) in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission. ESI assesses the sustainable use of natural resources by benchmarking the environmental performance at the national level. The index evaluates a nation's potential to avoid major environmental deterioration in terms of natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons and a society's capacity to improve its environmental performance over time (Esty *et al.*, 2005). Complementary to ESI, the Environmental Performance Index (EPI) measures the effectiveness of the efforts undertaken for national environmental protection in 163 countries. EPI ranks countries in two broad policy categories: (i) environmental health, which measures environmental stresses to human health, and; (ii) ecosystem vitality, which measures ecosystem health and natural resource management (Emerson et al., 2010). The Environmental Vulnerability Index (EVI) is another example based on predicting the vulnerability of the environment of a country to cope with future hazardous events (Kaly *et al.*, 2004). The Dashboard of Sustainability is a tool, which was developed by the European Commission-Joint Research Centre (Ispra, Italy), designed to present complex relationships between economic, social and environmental issues for decision-making (Joint Research Centre, 2004). Furthermore, the Wellbeing of Nations, which was developed by the World Conservation Union (IUCN) and the International Development Research Centre, surveys 180 countries in terms of wellbeing assessment. Wellbeing assessment includes the indicators of health, population, wealth, education, communication, freedom, peace, crime, and equity, which constitute a Human Wellbeing Index (HWI), and the indicators of land diversity, protected areas, land quality, water quality, water supply, global atmosphere, air quality, species diversity, genetic diversity, energy use, and resource pressures, which constitute an Ecosystem Wellbeing Index (EWI). The two indices are then combined into a composite Wellbeing Index that measures the amount of stress each country's development places on the environment (Prescott-Allen, 2001). Lastly, the National Footprint Accounts calculate the ecological footprint and bio-capacity of individual countries and of the world (Global Footprint Network, 2006). As defined by Gasparatos, (2010), "a composite index is an aggregation of different indicators under a well-developed and pre-determined methodology" (Fig. 6). An indicator-based composite index serves many purposes, including to: (i) Identify the analysis of relevant issues, current states and future trends; (ii) Provide a necessary information base for the definition of objectives, goals and the actions required; (iii) Direct decision making and urban planning processes in terms of monitoring, assessing performance and controlling, and; (iv) Serve for communication between administrative bodies and the public, for the initiation of discussions and increasing awareness.

Although composite indices are useful in focusing on simplifying the problem by evaluating its various aspects, which can then be incorporated into a single comparable index, composite indices have some disadvantages that are summarised in Table 5.

Based on the Composite Indicators Methodology and User Guide proposed by the OECD (2008), the construction of indicator-based sustainability composite index involves the following steps:

Developing a theoretical framework: This step refers to the definition of the environmental phenomenon to be measured and its sub-components. The theoretical framework of the index is based on an in-depth review of the literature. A theoretical framework also provides a basis for determining the relevant indicators that describes the measured phenomenon. This step also involves expert and stakeholder consultations in order to provide multiple viewpoints to increase the robustness of the index.

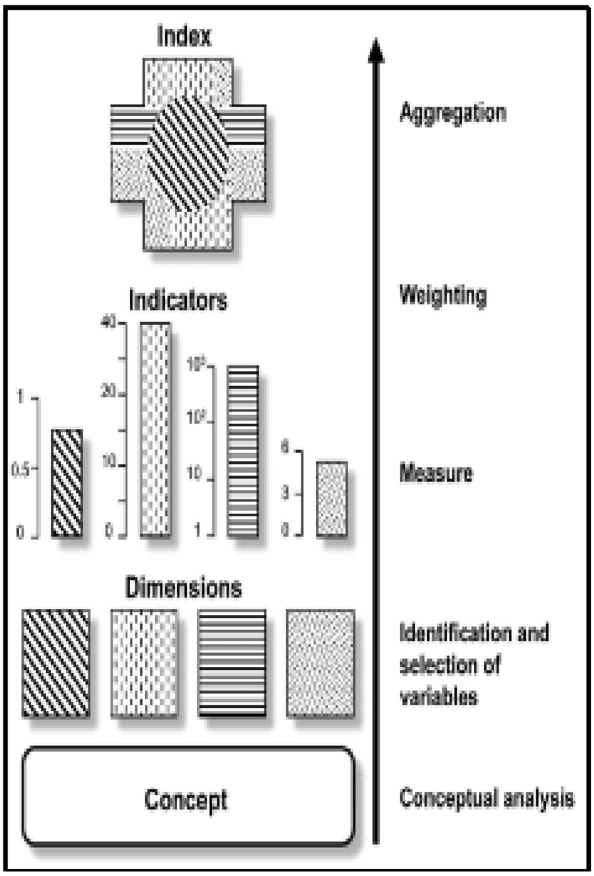

Fig. 6: Construction of index (Boulanger, 2008)

Table 5: Prospects and constraints of composite index (Saisana and Tarantola, 2002)

Prospects	Constraints
Summarise complex or multi-dimensional issues, in view of supporting decision-makers	May send misleading policy messages, if poorly constructed or misinterpreted
Are easier to interpret than trying to find a trend in many separate indicators	May invite drawing simplistic policy conclusions, if not used in combination with the indicators
Facilitate the task of ranking countries on complex issues in a benchmarking exercise	May be misused (i.e. to support the desired policy), if the construction process is not transparent and lacks sound statistical or conceptual principles
Assess progress of countries over time on complex issues	The selection of indicators and weights could be the target of political challenge
Reduce the size of a set of indicators or include more information within the existing size limit	May disguise serious failings in some dimensions of the phenomenon, and thus increase the difficulty in identifying the proper remedial action
Place issues of countries performance and progress at the centre of the policy arena	May lead wrong policies, if dimensions of performance that are difficult to measure are ignored
Facilitate communication with ordinary citizens and promote accountability	

Selecting indicators and data collection: This step involves selection of the indicators that are linked to the theoretical framework. An indicator is a statistical measure of relevant phenomena that pictures current conditions or changes in order to set goals, strategies and solutions (Heink and Kowarik, 2010). As the most important part of index construction, indicator selection needs to be based on the following dimensions of measurement, as summarised by Singh *et al.,* (2009):

- What aspect of the sustainability does the indicator measure?
- What are the techniques and methods employed for the construction of index (i.e., quantitative or qualitative, subjective or objective, cardinal or ordinal, one-dimensional or multidimensional?
- Does the indicator compare the sustainability measure (a) across space or time and (b) in an absolute or relative manner?
- Does the indicator measure sustainability in terms of input (means) or output (ends)?
- Clarity and simplicity in its content, purpose, method, comparative application and focus.
- Data availability for the various indicators across time and space.
- Flexibility in the indicator for allowing change, purpose, method and comparative application.

This step also includes data collection process for the selected indicators. There are two kinds of environmental data in the composition of the index: (i) Objective data, which are based on observations extracted from the monitoring stations, and; (ii) Subjective data, which are based on people's perceptions of contamination that are extracted from census data (Montero *et al.,* 2010).

Imputation of missing data: In order to provide a complete dataset, this step is applied to address the issue where the data is missing. There are two general methods for dealing with missing data. First method is case deletion, which is based on omitting the missing data from the analysis. The other method is based on providing a value for each missing data. In this method, the missing data values are generated through single imputation (e.g., mean/median/mode substitution), regression imputation, expectation-maximisation imputation, or multiple imputations (e.g., Markov Chain Monte Carlo algorithm).

Multivariate analysis: Multivariate analysis is used to investigate the overall quality of the data set and the soundness of the procedures applied in the construction of the index. This step includes the statistical analysis of the indicators in order to investigate the degree of correlation to each other. Different statistical methods can be used including: Principal Components Analysis, Factor Analysis, Cronbach's Coefficient Alpha, Cluster analysis, Pearson's correlation coefficient and Spearman's rank correlation coefficient. The result shows whether there are any indicators that measure the same or similar aspects that need to be excluded or replaced with some other suitable indicator measures.

Normalisation of data: In this step, a normalisation procedure is applied to the indicator set so as to convert the different indicator units into a common scale. The commonly used normalisation methods are: (i) Ranking which allows the performance of indicators to be followed over time in terms of relative positions, (ii) Standardisation which converts indicators to a common scale with a mean of zero and standard deviation of one, (iii) Min-Max which allows indicators to have an identical range by subtracting the minimum value and dividing by the range of the indicator values, and; (iv) Categorical scale which assigns a score for each indicator.

Weighting and aggregation: Weighting procedure reflects the importance given to the indicators comprising the index or the substitution rates between them. Different weighting methods can be used including: statistical models (i.e., factor analysis, data envelopment analysis, unobserved components models), and participatory methods (i.e., budget allocation, analytic hierarchy processes). Furthermore, weights can be determined based on expert opinion that is familiar with policy priorities and theoretical backgrounds. Aggregation procedure refers to the grouping of all the indicator scores into a composite index score. Different aggregation methods are possible: summing up (linear aggregation), multiplying (geometric aggregation) or aggregated using non-linear techniques (multi-criteria analysis).

Robustness and sensitivity: A sensitivity analysis is needed to assess the robustness of the composite index in terms of the choice of normalisation, weighting, and aggregation methods.

Visualisation of the results: This step involves the interpretation of the findings in order to provide a clear and accurate presentation of index results. Many visualisation techniques exist such as tabular format, bar or line charts, ranking or dashboards.

CONCLUSION

During the last several decades, the quality of natural resources and their services have been exposed to significant degradation from increased urban populations combined with the sprawl of settlements, development of transportation networks and industrial activities (Dorsey, 2003; Pauleit *et al.*, 2005). As a result of this environmental degradation, a sustainable framework for urban development is required to provide the resilience of natural resources and ecosystems. Sustainable urban development refers to the management of cities with adequate infrastructure to support the needs of its population for the present and future generations as well as maintain the sustainability of its ecosystems (UNEP/IETC, 2002; Yigitcanlar, 2010). One of the important strategic approaches for planning sustainable cities is 'ecological planning'. Ecological planning is a multi-dimensional concept that aims to preserve biodiversity richness and ecosystem productivity through sustainable management of natural resources (Barnes *et al.*, 2005). As stated by Baldwin (1985), "ecological planning is the initiation and operation of activities to direct and control the acquisition, transformation, disruption and disposal of resources in a manner capable of sustaining human activities with a minimum disruption of ecosystem processes". Therefore, ecological planning is a powerful method for creating sustainable urban ecosystems.

Contemporary ecological planning, however, has been receiving heavy critics as its inspired from the ecological modernisation theory, where the theory presents a complex understanding of post-industrial society, the lynchpin of the critics involves technological innovation (Mol, 2000). According to Fisher and Freudenburg (2001), "there are two main ways that the expectations of ecological modernization differ from those of most of the past work on society–environment relationships. First, the theory explicitly describes environmental improvements as being economically feasible; indeed, entrepreneurial agents and economic/market dynamics are seen as playing leading roles in bringing about needed ecological changes. Second, in the context of the expectation for continued economic development, ecological modernization depicts political actors as building new and different coalitions to make environmental protection politically feasible". On the other, many scholars who believe that ecological modernisation, or what some call 'sustainable capitalism', is not possible (O'Connor, 1994; Pellow *et al.*, 2000). On this point, Giddens, (1998) and Leroy and Tatenhove, (2000) argue that ecological modernisation skirts some of the main challenges ecological problems pose for social democratic thought and that, as a result, the theory is 'too good to be true'. Mol and Spaargaren, (2000) and Fisher and Freudenburg, (2001) provide an extended review on these critics.

The literature findings indicate that closely monitoring and assessing the impacts of human activities on the environment and its ecosystems are critical. Fortunately at present there are numerous applications available for this purpose. They are used in various scales from global to supra-regional (supra-macro level), national to regional (macro), city to district (mezzo), neighbourhood to street (micro), and parcel to building (supra-micro). This paper provided conceptual foundations and best practice examples in these scales, and argues that in order to explore the city as an ecosystem and investigate the interaction between urban ecosystem and human activities, a holistic urban ecosystem sustainability assessment approach is required. Urban ecosystem sustainability assessment serves as a tool that helps policy and decision-makers in improving their actions towards sustainable urban development. Several methods are used in urban ecosystem sustainability assessment and among them sustainability indicators and composite indices are the most commonly used tools for assessing the progress towards sustainable land use and urban management (Yigitcanlar and Kamruzzaman, 2014). Currently, a variety of composite indices are available to measure the sustainability at the local, national and international levels. However, the main conclusion drawn from the literature review is that they are too broad to be applied to assess local, micro and supra-micro level sustainability and no benchmark value for most of the indicators exists due to limited data availability and non-comparable data across countries. Moreover, assessment indices focusing on different scale need to be integrated with each other—the way that everything on the globe is integrated with each other. This brings the challenge of developing inter-scaled assessment tools and models that actually provide data and outputs for the next scale. Furthermore, Mayer (2008) advocates that by stating “as different as the indices may seem, many of them incorporate the same underlying data because of the small number of available sustainability datasets”. Mori and Christodoulou, (2011) also argue that this relative evaluation and comparison brings along biased assessments, as data only exists for some entities, which also means excluding many nations from evaluation and comparison.

There is, thus, a need for developing an accurate and comprehensive micro-level urban ecosystem sustainability assessment method that also have the capability to be integrated with larger scale assessment tools. Some scholars provide useful insights in to develop such models. For instance, Nardo *et al.*, (2005), Yigitcanlar and Dur (2010), Dizdaroglu *et al.*, (2012) and Dur *et al.*, (2014) suggest practical ways such as adopting an approach that uses a method to utilise indicators for collecting data, designate certain threshold values or ranges, perform a comparative sustainability assessment via indices at the micro-level, and aggregate these assessment findings to the local level and then to regional and other more broad levels. Hereby, through this approach and modelling perspective, it is possible to produce sufficient and reliable data to enable comparison at the local level, and provide useful results to inform the local planning, conservation and development decision-making process to secure sustainable ecosystems and urban futures (Yigitcanlar *et al.*, 2015) and at the same time provide data and outputs for further analysis at the regional and national levels (Dizdaroglu and Yigitcanlar, 2014; Dur and Yigitcanlar, 2014). This method is most likely to provide generation of more informed policies and relevant actions in achieving a sustainable development, protecting and enhancing ecosystems health, and supporting the planning and development of sustainable cities of tomorrow.

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How to cite this article: (Harvard style)

Yigitcanlar, T.; Dizdaroglu, D., (2015). Ecological approaches in planning for sustainable cities: A review of the literature. Global J. Environ. Sci. Manage., 1 (2): 159-188.